Leaf Glyph
Visualizing Multi-dimensional Data with Environmental Cues

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Abstract: In exploratory data analysis, important analysis tasks include the assessment of similarity of data points, labeling of outliers, identifying and relating groups in data, and more generally, the detection of patterns. Specifically, for large data sets, such tasks may be effectively addressed by glyph-based visualizations. Appropriately defined glyph designs and layouts may represent collections of data to address these aforementioned tasks. Important problems in glyph visualization include the design of compact glyph representations, and a similarity- or structure-preserving 2D layout. Projection-based techniques are commonly used to generate layouts, but often suffer from over-plotting in 2D display space, which may hinder comparing and relating tasks.
We introduce a novel glyph design for visualizing multi-dimensional data based on an environmental metaphor. Motivated by the humans ability to visually discriminate natural shapes like trees in a forest, single flowers in a flower-bed, or leaves at shrubs, we design a leaf-shaped data glyph, where data controls main leaf properties including leaf morphology, leaf venation, and leaf boundary shape. We also define a custom visual aggregation scheme to scale the glyph for large numbers of data records. We show by example that our design is effectively interpretable to solve multivariate data analysis tasks, and provides effective data mapping. The design also provides an aesthetically pleasing appearance, which may help spark interest in data visualization by larger audiences, making it applicable e.g., in mass media.

1 INTRODUCTION

Glyph-based data visualization has a long tradition in Information Visualization research and application. The basic idea in glyph visualization is to map data properties to visual properties of some appropriately designed visual structure. By the interplay of the different visual properties, each glyph then represents a data record. Many data records can be compared by appropriately laid out glyph displays. Glyph visualization, like other areas in Information Visualization, can be considered both a science and an art. Specifically, the design of glyphs may be inspired intuitively by common, well-known shapes or icons. For example, Chernoff faces were inspired by face properties, and sticky figures by abstraction of human body shapes.

A subset of the designs studied in Information Visualization to date has been inspired by nature. For example, tree structures have inspired hierarchical node-link diagrams. As another example, the notion of information landscapes or terrains is also borrowed from nature. There is reason to believe that the human visual sense, due to long evolutionary processes, is highly trained in recognizing, distinguishing and comparing natural forms. These visual recognition processes typically work well even in low illumination conditions, or in presence of partial occlusion of natural objects. By background knowledge and experience, humans are able to efficiently recognize natural shapes, also often in cases where only parts of the shape or their boundary are visible.

Based on this motivation, we investigate the design space for leaf shapes as natural metaphors for data glyphs. From observing leaves in nature, it is clear that there is a large variability in the different types and forms of leaves that exist. Overall leaf shape, shape boundary, and shape interior all comprise several visual parameters that can in principle, be used to map data to generate glyphs. To the best of our knowledge, this is the first work to systematically study the design space of leaf-based glyph visualization, and identify an encompassing set of leaf variables to map data to. In conjunction with appropriate glyph layouts (based e.g., on projection), and visual aggregation techniques, effective and intuitive

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data displays can be realized. Our rationale for using leaf-based data visualization is two-fold. First, the design space is large, giving ample opportunities for the visualization expert to map data variables to visual variables. As will be discussed, our variable space amounts to more than 20 different visual variables than can be controlled. While we have not formally evaluated the effectiveness of these variables or their combinations, we presume this is a large design space from which appropriate effective selections can be found. Second, we propose that nature-inspired designs, by their potential aesthetic appearances and familiarity, can be suited to spark interest in visual data analysis for wider audiences, e.g., for use in mass media. Also, it resonates well with visualization of environmental data, as has been previously demonstrated, e.g., by a respective infographic used by OECD (see Section 2.2).

The remainder of this paper is structured as follows. In Section 2, we discuss glyph-based and nature-inspired data visualization approaches. Section 3 defines the design space for leaf glyphs, based on identification of main visual leaf properties which are candidates for data mapping. Then, in Section 4, we define several visual aggregation schemes to scale 2D glyph layouts for large numbers of data points. Section 5 then applies our design to several data sets. By exemplary data analysis cases, we demonstrate the principal applicability of our approach. Finally, Section 6 summarizes our work and outlines future research in the area.

2 RELATED WORK

Our work extends the design space of two existing branches of research by introducing a compact data representation making use of environmental cues. The related work is, therefore, split into two parts. The first part covers the area of space efficient visualization techniques, namely, data glyphs. The second part addresses research using environmental cues to convey data. We do not address research in the area of computer graphics, since this work mainly focuses on photo-realistic representation of the environment. We refer the interested reader to a summary work about this topic by Deussen and Lintermann (Deussen and Lintermann, 2005).

2.1 Glyphs

In the literature, there exists a large variety of glyph designs. Elaborate summaries can be found in (Borgo et al., 2012) (Ward, 2008). To come up with a comprehensive categorization we make use of Ward's classification of data glyphs (Ward, 2008). In his research he distinguishes between three different ways a data point can be mapped to a glyph representation.

First, Many-to-One Mapping: All data dimensions and their respective value are mapped to a common visual variable. Therefore, these designs can be systematically created by choosing the most effective visual variable for a certain task. Additional guidance is given by Cleveland et al. with a ranking of visual variables (Cleveland and McGill, 1984). Well-known examples making use of a position/length encoding are star glyphs (Siegel et al., 1972), whisker and fan plots (Pickett and Grinstein, 1988)(Ware, 2012), or profile glyphs (Du Toit et al., 1986). The designs just differ in their layout of the dimensions (i.e., circular or linear) and some minor variations like the presence or absence of a surrounding contour line. Other glyph designs make use of color encodings to represent the data value. Clock glyphs (Kintzel et al., 2011) map the dimensions in a radial fashion, whereas pixel-based glyph designs (Levkowitz and Herman, 1992) layout the dimensions linearly. Of course, color cannot convey the data as accurate as a position/length encoding (Fuchs et al., 2013), however, for certain tasks like spotting outliers the color encoding is a reasonable choice. There is even a design mapping the data values to the angle of its rays. Sticky figures (Pickett and Grinstein, 1988) use the visual variable orientation, which is not so accurate in communicating exact data values. However, when used as an overview visualization the designs convey individual shapes, which are perceived as a whole nicely approximating the underlying data point.

Second, One-to-One Mapping: Each dimension is mapped to a different visual variable. Probably, the most well-known representations here are Chernoff faces (Chernoff, 1973). The single data values are mapped to face characteristics, like the size of the nose or the angle of the eyebrows. Other more exotic designs are bugs (Chuah and Eick, 1998) (changing the shape, length or color of wings, tails and spikes), or hedgehogs (Klassen and Harrington, 1991) (manipulating the spikes by changing the orientation, thickness and taper). The major drawback of these kinds of glyph representations is that they are often sensitive to the order by which the data dimensions are mapped to visual variables. Variation of the order could significantly change the final glyph representation and its visual perception by users. Additionally, measuring differences between single dimension values within a data point is typically a difficult task, as the analyst has to compare different kinds of visual variables with each other (e.g., compare length with

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saturation or angle, etc.)

Third, One-to-Many Mapping: The dimensions are represented by two or more visual variables. This redundant mapping can be useful to strengthen the perception of individual dimensions. For example, in star or profile glyphs the dimensions can be additionally encoded by coloring the single data rays. Clock glyphs can make use of an additional length encoding for the single colored slices to encode the underlying data values more accurately.

2.2 Environmental Cues

Visualizations making use of environmental cues need not necessarily be glyph representations. Stefaner uses an abstract tree layout to show the editing history of Wikipedia entries represented as single branches (Stefaner, 2014a). The branches grow to the right whenever people decided to delete an article or to the left in the other case. The resulting tree nicely summarizes 100 articles with the longest discussion whether to keep them or not. Another tree-based approach in combination with leaves visualizes poems in a more artistic way (Müller, 2014). The branches of the tree are invisible just dealing as an anchor point to arrange the glyphs. Each word in the poem is represented with a leaf glyph and attached along the tree structure. The work is not eligible of representing the text data accurately but tries to illustrate a creative unique picture or fingerprint of the underlying poem.

A more data-driven glyph design is the botanical tree (Kleiberg et al., 2001), which again uses a 3D tree layout to represent hierarchical information. The single nodes are represented as fruits. The authors argue that people can more easily identify single nodes in this visualization compared to a more abstract representation because they are used to detect fruits or leaves on shrubs or trees. A 2D visualization using a botanical tree metaphor are so-called Contact-Trees (Sallaberry et al., 2012) which show relationships in data, e.g., contacts between persons. The branches consist of single lines representing an attribute in the data, e.g., a longer line refers to an older tie between people. Finally, fruits or leaves are added to the tree according to some data property, e.g., the kind of relation between people (friends, co-workers etc.) However, the fruits and leaves are highly abstract representations (mainly colored dots) and their shape does not change according to some data characteristics. The OECD's Better Life Index visualization (Stefaner, 2014b), on the other hand, systematically changes the appearance of the single flower glyphs used to represent data. Stefaner uses such environmental cues to visualize multi-dimensional data about country characteristics. Each country is represented by one flower. The petals encode the different economic branches with varying sizes and lengths for the corresponding values. The flowers are arranged according to their weighted rank across all dimensions. People can change the layout by changing the weights of the dimensions or simply focusing on just one dimension.

We contribute to this body of existing work with the definition of a highly detailed leaf glyph, which closely follows the main morphological and functional variations among leaves. It is able to effectively map data variables. We also provide a custom aggregation scheme to scale leaf layouts for large number of records.

3 ENVIRONMENTAL GLYPH

According to Biological literature, leaves may be categorized by their function or usage in the environment (Beck, 2010). For our purposes, we divide leaves according to their shape (or morphology). The overall appearance of a leaf consists of the combination of (1) the overall shape type, (2) the boundary details, and (3) the leaf venation. We consider these three aspects as the main dimensions for controlling the leaf glyph by mapping data. As a result we come up with a design space structured along the overall leaf shape, which we discuss next.

3.1 Leaf Shape Design Space

Following Palmer who pointed out: "Shape allows a perceiver to predict more facts about an object than any other property" (Palmer, 1999), this visual variable should be used for the most important data dimension. In the environment, there exists a nearly endless amount of different leaf shapes since each leaf is unique. However, it is possible to distinguish leaves according to their overall shape (Deussen and Lintermann, 2005). A first categorization can be done between conifer and deciduous leaves.

Conifer leaves can be found for example at fir or pine trees and have a thin long needle-like shape. Therefore, they do not offer much space for a venation pattern, which we want to use later for mapping additional attributes (e.g., Acicular leaves). Since the differences in shape are quite small for the different kinds of this group and the provided area is limited due to the distorted aspect ratio, we do not consider them in our design space.

Deciduous leaves cover a large group of different

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shapes and can again be further divided into four subcategories (Deussen and Lintermann, 2005).

Pinnate and *palmate* compound leaves are shapes, which consist of several smaller leaflets attached to a shared branch (e.g., Alternate, or Odd and Even Pinnate leaves etc.). In order to avoid any misinterpretation between single leaflets at a branch and individual leaves, we discard this group from our final design space. However, these kinds of leaves seem an appropriate representation to visually summarize multiple data points where one leaflet corresponds to a single leaf.

Lance-like leaves have a parallel venation and are thin and long, similar to conifer leaves. Therefore, it is difficult to distinguish different kinds of these leaves since the differences in the overall shape are limited. Like the conifer leaves, we do not keep them in our design space because of the limited area to map a venation pattern, and because of possible confusion of different lance-like shapes.

Leaves with *net veins* or *reticulate* venation patterns encompass the largest group of deciduous leaves with a big diversity in shape. We restrict ourselves to the most common leaf shapes for this category to avoid misinterpretation of intermediate structures, which could not clearly be distinguished. Additionally, we focus on leaves with a big surface to show venation patterns and small stems to save space. Leaves similar to Flabellate, Unifoliate, etc. will, therefore, not be considered.

The most important requirement for shapes in visualizations is that they should be easily distinguishable. Therefore, our final design space covers elliptic (e.g., Ovate, Obtuse, Obcurdate etc.), circular (e.g., Orbicular), triangular (e.g., Deltoid), arrow-like (e.g., Hastate, Spear-shaped etc.), heart-like (e.g., Cordate, Deltoid etc.), two variations of tear-drop like (e.g., Acuminate, Cuneate etc.), wave-like (e.g., Pinnatisect), and star-like (e.g., Palmate, Pedate, etc.) shapes. Figure 1 illustrates the nine different leaf shape categories covered by our design space. In Section 5 we will introduce a heuristic to map data points to leaf shapes, based on the idea of representing outlying points by the more jagged leaf shapes; conversely, non-outlying points will be represented by the more regular or smooth leaf shapes.

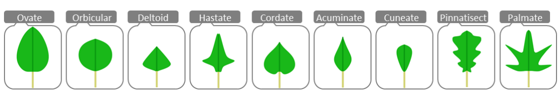

Figure 1: **Leaf Shapes:** Selected from our overall design space, these are the shapes used in our final glyph design. From left to right: Elliptic, circular, triangular, arrow-like, heart-like, tear drop up, tear drop down, wave-like, and star-like shapes.

We take these categories as a starting point and further extend them by mapping additional attribute dimensions to the width and the height of the glyph, scaling the overall shape. Therefore, similar shapes according to a certain data characteristic can look different because of the varying aspect ratio. However, the individual shape categories can still be distinguished (Figure 2). Because of this decision, we will deviate from the precise environmental reference, where leaves typically show a homogeneous aspect ratio. However, we thereby are able to encode additional data dimensions. Note that we do not want to represent leaves as accurate as possible (or even photo realistic), but use their expressiveness to visualize data.

Figure 2: **Leaf Scaling:** The Palmate leaf shape is scaled using either the width (middle), or the height (right) of the glyph. Even after scaling, the glyph can still be recognized as a star-like leaf, although the precise environmental reference to the Palmate leaf is reduced.

3.2 Leaf Boundary Design Space

Basically, the boundary (or margin) of a leaf can be described as either serrated or unserrated. *Unserrated* boundaries have a smooth contour adapting to the overall leaf shape. *Serrated* boundaries are toothed with slight variations depending on the size of teeth, their arrangement along the boundary, and their frequency. Of course, there are more detailed differences and variations in nature. However, especially in overview visualizations (the major domain of data glyphs), distinguishing between small variations of the contour line of a leaf shape is nearly impossible. We therefore focus on just the two main boundary categories of teethed or smooth (serrated or unserrated). For mapping data values to the leaf boundary, we distinguish between a smooth and a toothed contour line and vary the width, height, and frequency of the teeth according to the underlying data value (Figure 3).

3.3 Leaf Venation Design Space

We also control the leaf venation pattern as to map additional data variables to the glyph. Several main leaf venation patterns exist, which differ in their overall structure within the leaf. A rough distinction can

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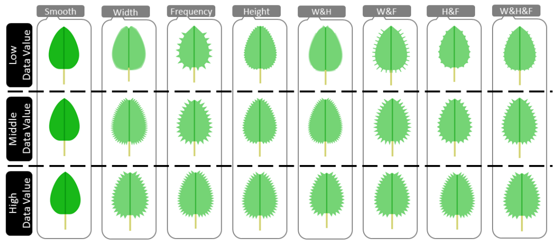

Figure 3: **Leaf Boundary:** Modifying the boundary in our design is realized by changing the frequency, the height, or the width of the boundary serration (teeths). Combinations of these three variables are possible and increase the expressiveness of the glyph. The figure illustrates all possible combinations for low, middle, and high data values for an elliptically shaped leaf glyph.

be made between single, not intersecting (e.g., Parallel), paired (e.g., Pinnate), or net-like (e.g., Reticulate) veins. The venation is perceived as an additional texture for the glyph and further increases the glyph expressiveness. Since it is hard to find a natural order within this texture, we propose to use the venation type for visualizing qualitative (or categorical) data, similar than the overal leaf shapes discussed in Section 3.1. Within a given venation type, we may also encode numeric data. This works as follows. Generally, the leaf is split in the middle by a main vein, with small veins growing from there in a given direction (angle). For mapping numerical data, we may either control this *angle of the veins* branching out from the main vein. An alternative is to control the *number of veins* shown on the surface Figure 4. As a result, we come up with a venation texture able of encoding categorical and numerical data.

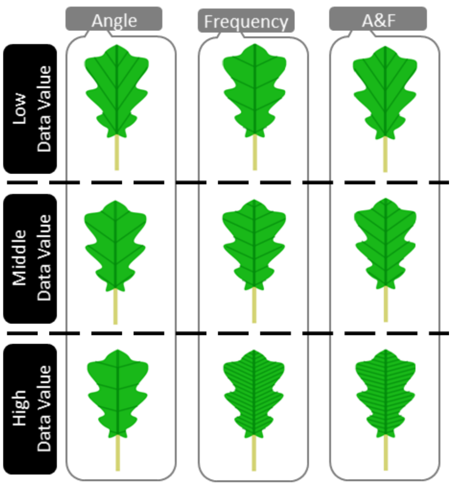

Figure 4: **Leaf Venation:** The texture for the venation system can either be created by mapping data values to the angle or frequency of the veins separately, or by combining the two. The figure illustrates all possible combinations for low, middle, and high data values for a wave-like leaf shape.

3.4 Summary

Besides modifying the leaf shape given by morphology, boundary and venation, further dimensions can be assigned to the color hue or saturation of the glyph. Of course, the designer has to pay attention to the contrast between the venation texture and the background color. Additionally, orientation of the glyph in the display can be used to encode further numeric information. We draw a short stem to each leaf shape, showing its orientation. Finally, it is also possible to modify the stem's width or height as well.

This represents a comprehensive design space for mapping data to leaf glyphs, controlled by 12 categorical and 14 numeric parameters, summing up to 26 variables altogether (see Table 1 for an overview of all variables.) We propose this design space as a toolbox from which the designer may select visual variables as appropriate. The number of 26 parameters is considered more a theoretical upper limit of data variables that we can show. We expect not all visual parameters in this design space to be of the same expressiveness; but some variables may be more effective than others, and may not all be orthogonal to each other. Careful choice should be done in selected and prioritizing the variables. An option is of course always, to redundantly code data variables to different glyph variables, to emphasize perception of important data variables. In Section 5, we will illustrate by practical examples, how glyph variables can be combined to form data displays.

4 LEAF GLYPH AGGREGATION

When visualizing large data sets, leaf glyphs are prone to overlap in the display, reducing the effective-

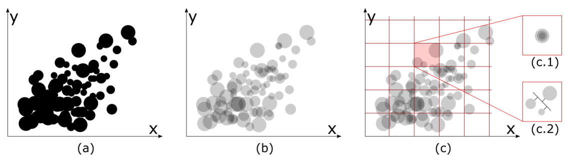

Figure 5: **Main principles of aggregating point data in a scatterplot.** In (a), point data is visualized in a scatterplot. The point data is represented in three different dimensions: small, medium, and large. Differences and data values can barely be identified since the visualization is cluttered. To overcome this issue, we apply transparency in (b), partially solving the issue of clutter. In (c), grid-based aggregation is applied. All points that fall within the same cell are aggregated. (c.1) shows a prototype-oriented aggregation: Points are stacked in order to be able to distuinguish them. (c.2) shows abstraction by visual aggregation: Points are aligned along a line.

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Table 1: Summary of the parameters of our glyph design. It comprises 14 numeric and 12 categorical variables, which form the theoretic upper limit for the expressiveness of our glyph. Note that in practice, these variables are expected to not all be orthogonal, and comprise different perceptional performance, depending also on the data.

Leaf Design	Numeric Variables	Categorical Variables
Shape	2 (x/y scale)	9 (selected morphologies)
Boundary	3 (frequency, width, height of teeth)	–
Venation	2 (number, angle of child veins)	3 (parallel, paired, net)
Other	8 (hue, saturation, orientation, x/y position, stem width/height)	–
Sum	15	12

ness of perceiving data from individual glyphs. Figure 5 outlines possible solutions by example of a scatterplot. The scatterplot (a) visualizes point data using three different point dimensions: small, medium, and large. An increasing amount of visualized points produces significant clutter resulting in perceptional problems – the user is not able to distinguish between data points properly. We point out three different aggregation techniques: (b) Alpha Compositing, (c.1) Prototype Generation, and (c.2) Abstraction. First, we apply transparency in (b) to provide a visually pleasing representation that also reveals differences between data points. In some cases, the application of transparency is not enough. For example, if multiple data points share the same position, the opacity might sum up until no difference is perceivable. Therefore, we propose in (c) two different aggregation techniques that build on top of transparency and the application of a grid-based aggregation. Specifically, we place a user-defined grid on top of the visualization. All data points sharing the same cell are aggregated. In (c.1), all included data points are stacked so that the different dimensions can still be perceived. In contrast, (c.2) creates a new representation instead: All included data points are aligned in a clutter-free manner along a line.

These effects can at the same time be perceived in nature: leaves can overlap or coincide with others. We adapt the proposed aggregation techniques and extend them in order to find a representative aggregate glyph which summarizes multiple leaf glyphs.

In Figure 6 and Figure 7 we point out the application of the aggregation techniques – Alpha Compositing, Prototype Generation, and Abstraction – with respect to nature. We next explain them in terms of their counterpart in nature, and apply them to our visualization of leaf glyphs.

4.1 Alpha Compositing

We use Alpha Compositing (Porter and Duff, 1984) to reveal details on overlapping glyphs by applying transparency. This technique describes the process of

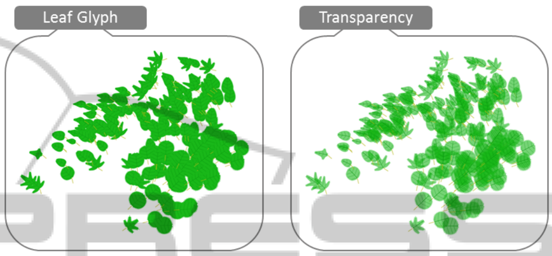

Figure 6: **Aggregation by Alpha Compositing.** When multiple leaves overlap or coincide, we are not able to distinguish properly between their shapes and related characteristics. To overcome this issue, we propose to apply alpha compositing. It reveals details by applying transparency to the leaves.

combining multiple, separately rendered images in order to provide a transparent appearance. The result of the application of transparency to the glyphs is shown in Figure 6.

As mentioned in Section 3, different leaf shapes and characteristics need to be taken into account. In nature, leaves own the characteristic that even when multiple leaves overlap, we perceive differences due to their diverse shape and color. To support this, we apply transparency to the leaves. Figure 6 presents the first results. The application of transparency works well, in our experience, for a limited amount of leaf glyphs. When too many leaves overlap, perceptional problems can arise: Since the transparency also aggregates, from a certain extent on, the glyphs can become occluded and not be distinguishable anymore. For this reason, we propose two additional aggregation techniques we observed in nature: Prototype Generation and Abstraction.

4.2 Prototype Generation

As mentioned above, transparency might not be enough when aggregating multiple glyphs. Therefore, we propose to additionally generate a prototype glyph that aggregates the characteristics of all considered glyphs. We apply a grid to the image space and aggregated all leaves whose calculated center point falls

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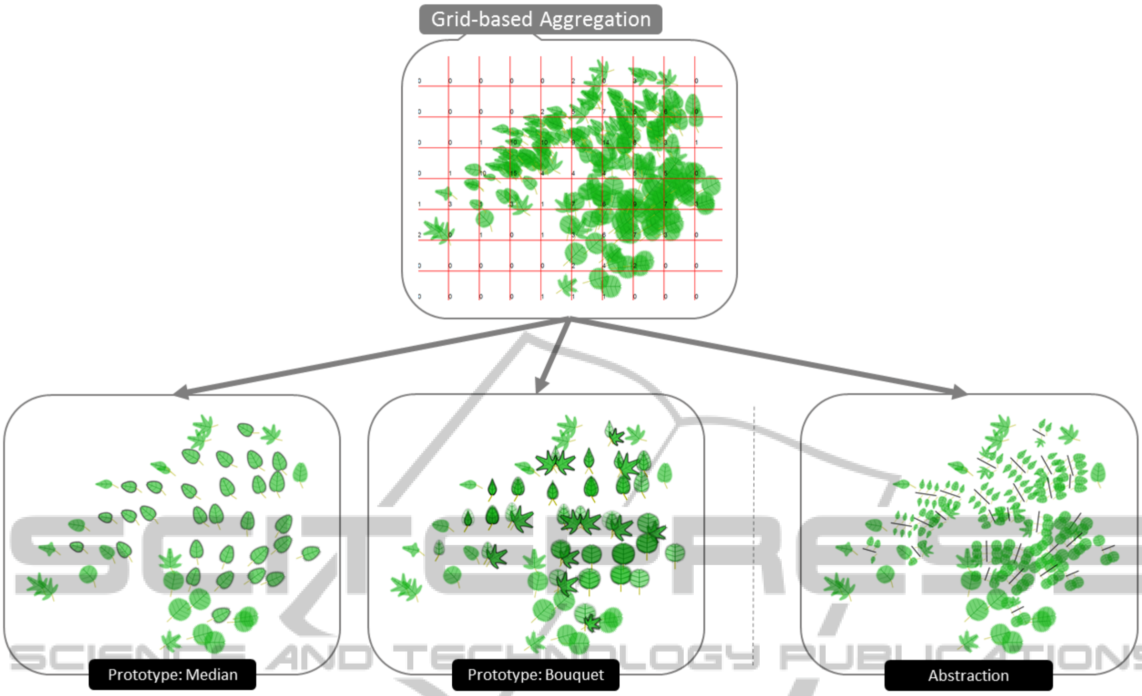

Figure 7: **Grid-based Aggregation.** We apply a grid to the visualization and calculate the center point of each leaf glyph, and aggregate all glyphs whose center points coincide within the same cell. Two different aggregations can be used: *Prototype Generation* and *Abstraction*. The first determines a representative glyph for the corresponding cell in the form of a median glyph or a bouquet glyph. The second creates (similar to what we observe in nature), a branch with multiple leaves based on the attributes of the considered leaves.

into the same grid cell; the cell dimensions are user defined. The glyph representing such cell can either be a representative of a statistical concept such as the median value of all coinciding glyphs or a bouquet which combines different leaf glyph types (analogous to different flower types). Figure 7 shows the result of both techniques, visualization of the median as well as the visualization in form of a bouquet. For both techniques, the transparency is preserved in order to be able to distinguish between different attribute values that determine the shape of a leaf glyph.

Our first proposed prototype is the representation of the median. We therefore create a new leaf glyph that has a simple appearance by means of its shape. We use the median venation, margin, and shape in order to describe a set of leaves that coincide in one cell.

Similar to a bouquet, we derive our second proposed prototype by combining and aligning all contained leaf glyphs. First, all leaf glyphs sharing the same shape are stacked using transparency as described in Section 4.1. Second, stacked leaf glyphs are aligned in a radial manner according to their shape. This means, while in the first step glyphs are stacked according to their shape, in the second step they are radially moved and aligned according to the shape classes as pointed out in Section 3. As a result, we get a representation similar to a bouquet.

4.3 Abstraction by Visual Aggregation

Based on the grid aggregation, we need to address issues that emerge when too many glyphs fall into one cell. Prototype generation may fail, if too many glyphs along too many different shapes are aggregated, and the visualized prototype may then suffer from clutter. Therefore, we propose abstraction by visual aggregation. We describe the new visual representation for an aggregated set of glyphs. Similar to growth characteristics of leaves we observe in nature, this aggregation technique represents an aggregated set of leaf glyphs as a new branch with multiple leaves on it. All leaf glyphs are aligned side-by-side along a branch according to Figure 7.

5 ILLUSTRATIVE APPLICATION

We defined an encompassing scheme to generate leaf glyph-based data visualizations for large data sets. We implemented the above described designs in an interactive system. We here exemplify results we obtained with three data sets. These results aim to show the principle applicability. Note that a thorough comparison against alternative glyph designs and user testing remain to be done in future work.

5.1 Forest Fire

The forest fire data set is available in the UCI machine learning repository (Cortez and Morais, 2007) and called *forest fire*. It contains data about burned areas of forests in Portugal on a daily basis for one year. Additionally, weather information is included, e.g., temperature, humidity, rain and wind conditions at respective points in time. This data set does not contain any categorical data which could be mapped to the leaf shape. Therefore, we initially clustered the data points with the DBSCAN algorithm (Han et al., 2011) and assign local or global outliers to different glyph shapes (Figure 8). Our idea is to map outliers to the more jagged leaf shapes, while non-outlier points get mapped to more regular or smooth shapes, thereby providing a first visual assessment of the degree of outlyingness for the data. Our analysis task is to find similarities between burned areas to be able to predict fires due to certain weather conditions.

First, we applied alpha compositing as an aggregation technique to get a rough idea of the data (Figure 9). We used one glyph for each data point and positioned them according to their temperature (y-axis) and humidity (x-axis) value in a common scatterplot layout. The orientation of the leaves illustrates the wind strength and color hue/saturation is used to encode the time (i.e., month) of the data point (i.e., green refers to the first half of the year (spring and summer), red to the second half (autumn and winter)). The amount of rain is mapped to the margin, and the venation pattern. The overall size of the glyph encodes the area of burned forest land after a logarithmic normalization.

Figure 9 clearly shows three clusters of data points separated by color (i.e., month). Most forest fires occur in the summer time (May - September) represented by yellow leaves. This cluster ranges from low to high temperature and humidity values, showing a visual correlation between the two. It seems that most leaves are pointing to the left indicating low wind conditions. A single maple leaf at the upper right corner represents an outlier, which is surrounded by smaller leaves pointing in the opposite direction. If we have a closer look at this data point we can see that the margin is smooth (no rain), the wind is strong (oriented to the right) and the temperature is high (y-position). With this understanding of the data, it is plausible that

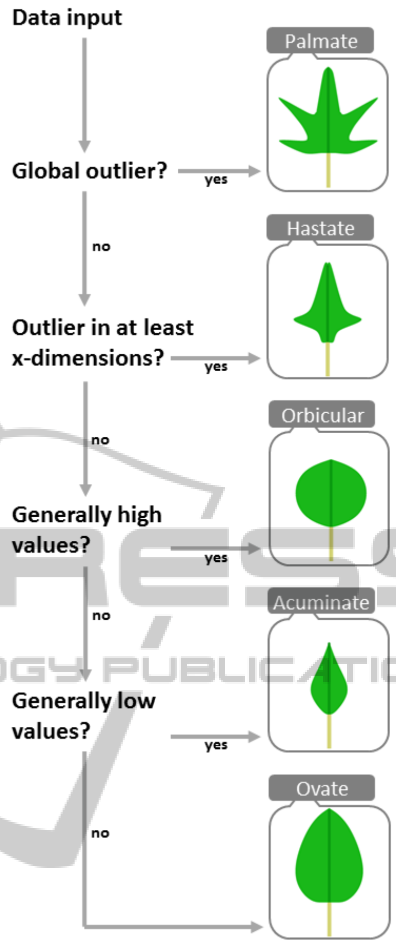

Figure 8: **Shape Categories:** Based on the results of the clustering we assign different leaf shape templates according to the data characteristics.

the burned forest area is so large. Low rain, high temperature, and strong winds all support the spread of a forest fire. Another interesting finding is the outlier highlighted with the label **1**. Compared to the other leaves, this is the only glyph with a highly serrated margin encoding a high amount of rain. It is interesting to see that the area of burned forests is relatively high although it rains a lot. Perhaps the higher wind strength is a possible reason, however, rain does not prevent bigger fires to happen.

For the other half of the year (red and green colors) the temperature is higher with lesser forest fires, which is a surprising fact. However, the size of these leaves especially in winter times (colored red) are relatively big and are oriented to the right (strong wind conditions). This visual correlation between temperature, wind condition and the size of burned areas is an expected finding since the wind is most often responsible for spreading fire in a certain direction.

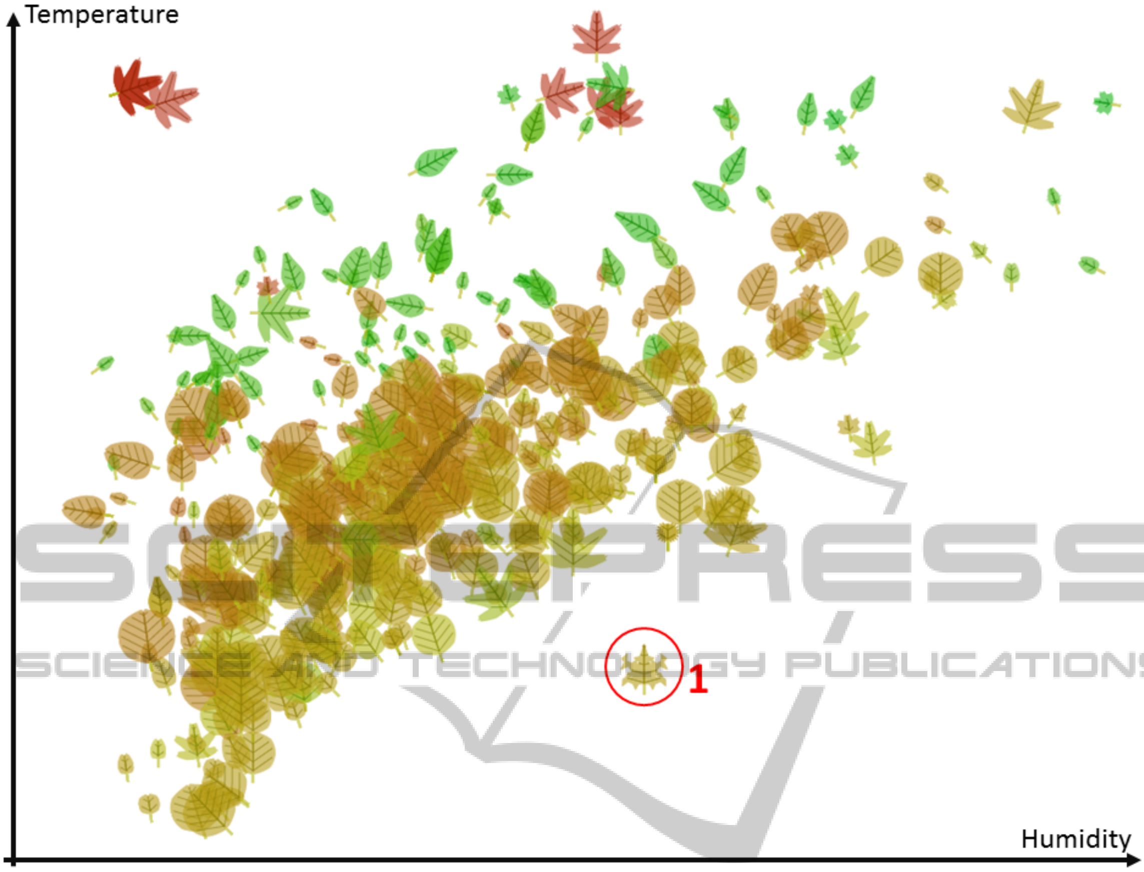

Figure 9: **Forest Fire Data Set:** We applied alpha compositing for aggregation to get a first overview of the data set. We used the following mapping to represent the multi-dimensional data: Shape ≙ local/global outlier, y-position ≙ temperature, and x-position ≙ humidity, color hue/saturation ≙ time (i.e., month), size ≙ area of burned forests, venation and margin ≙ rain, orientation ≙ wind.

Since we now understand the overall structure of the data, we switch to an alternative aggregation technique to better understand the highly cluttered area (Figure 10). Because of our prototype generation, we loose the orientation of the glyphs and, therefore, the wind condition. In the highly cluttered area in the middle of the plot, several different maple leaf shapes are now visible. They refer to outliers detected by our previous clustering algorithm. It is interesting to see that the temperature for these data points is relatively low with nearly no rain and mixed humidity. Typical indicators for fire, like high temperature, low humidity and high wind strengths seem not to be the main reason for the large burned forest areas. Perhaps other factors, e.g., the area or the coverage of fire stations, might be explaining factors here.

Of course, these findings would need to be substantiated by additional data considerations. Further information, e.g., the amount of firemen fighting the fire, the exact kind and amount of trees, or the time until the fire was recognized are important side factors not covered within the data. However, with our new glyph approach we were able to easily identify timely patterns, outliers, and similar behavior of data points.

5.2 Iris and Seeds

Figure 11 illustrates two well-known data sets (i.e., *iris* and *seeds*) from the UCI machine learning repository as an infographic representation. For both data sets, an initial k-means clustering is performed based on the number of classes within the data set. The clusters are then mapped to unique leaf shapes and projected to 2D space by Principal Component Analysis (PCA). As a last step the data dimensions are mapped to leaf glyph properties providing insights of the data. Due to the projection, some classes can already be distinguished. However, additionally assigning the clusters to different shapes helps to characterize the data more easily.

By mapping all data dimensions to glyph features,

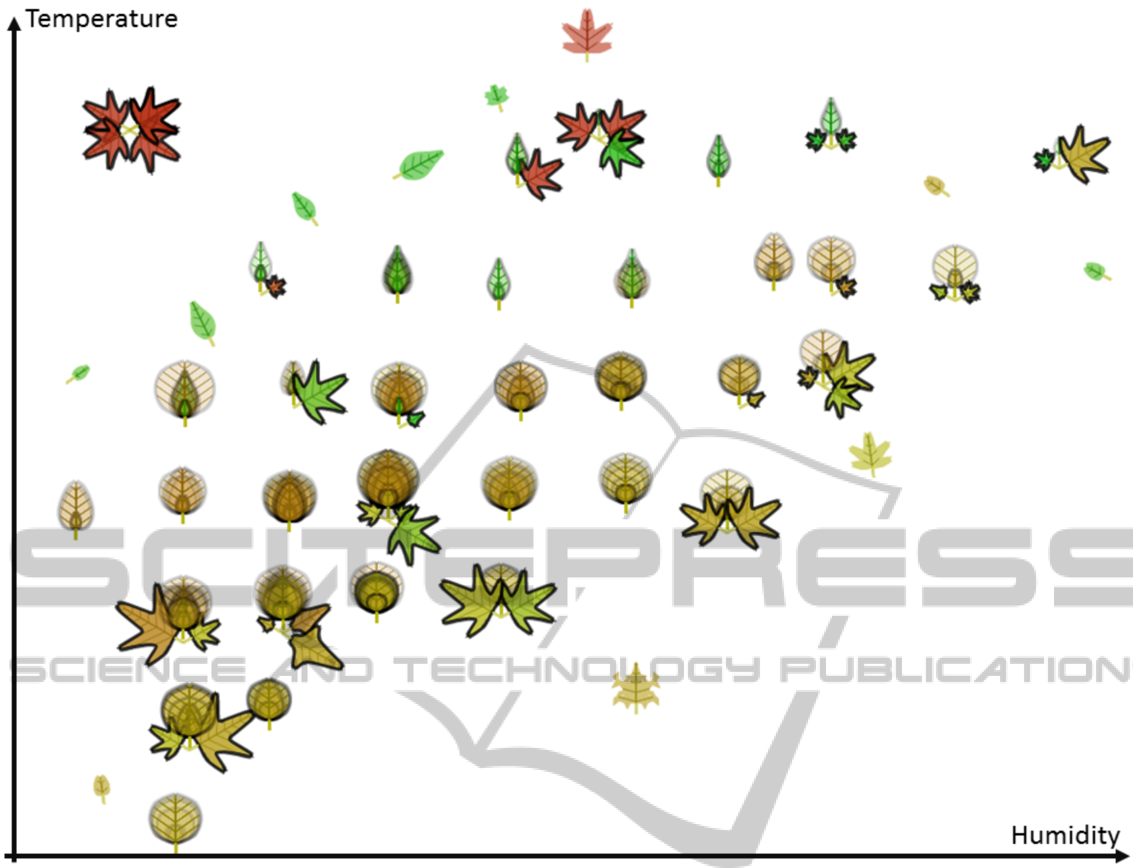

Figure 10: **Forest Fire Data Set:** We applied a prototype aggregation technique to reveal insights to the highly cluttered areas in the plot. Interesting to note are the relatively big outlier leaf shapes, which were not visible beforehand.

it is possible to extract more detailed information. In the seeds data set, there is a visual correlation between orientation (length of the grain) and venation frequency (width of the grain). The same thing is true for the color hue (asymmetry coefficient) and the y-position (1st principal component). The size (compactness) seems to slightly reflect the x-position (2nd principal component).

The iris data set is clearly divided into two different clusters by performing a PCA projection. However, the data contain three classes, which are mapped to the shape by performing a k-means clustering. The visualization clearly shows two classes within the single cluster on the left. There seems to be a high correlation between the sepal height and length, which are mapped to the height and length of the glyph respectively. Since no leaf shape gets rescaled, the ratio between the two is read similar. Within the three classes, there is an almost equal distribution of the petal length mapped to the color hue. Finally, the orientation represents the petal width, which highly correlates to the x-position (2nd principal component).

6 CONCLUSION AND FUTURE WORK

We introduced Leaf Glyph, a novel glyph design inspired by an environmental metaphor. Due to its natural and pleasing appearance, we expect users are likely to be able to discriminate data by shape and properties. The glyph is based on a naturally prominent shape, which should connect well to human perception, supposedly also under conditions of partial overlap. We systematically structured the leaf glyph design space. Specifically, we mapped data to the main properties of the leaf glyph: leaf morphology, leaf venation, and leaf boundary. Furthermore, we defined a custom visual aggregation to scale the glyph for large numbers of data records with respect to its counterpart in nature. Finally, we exemplified the applicability and effectiveness of our approach in a multivariate data analysis task.

This work is only the first step in studying the effectiveness of nature-oriented data visualization. While we believe leaf glyphs can form intuitive and

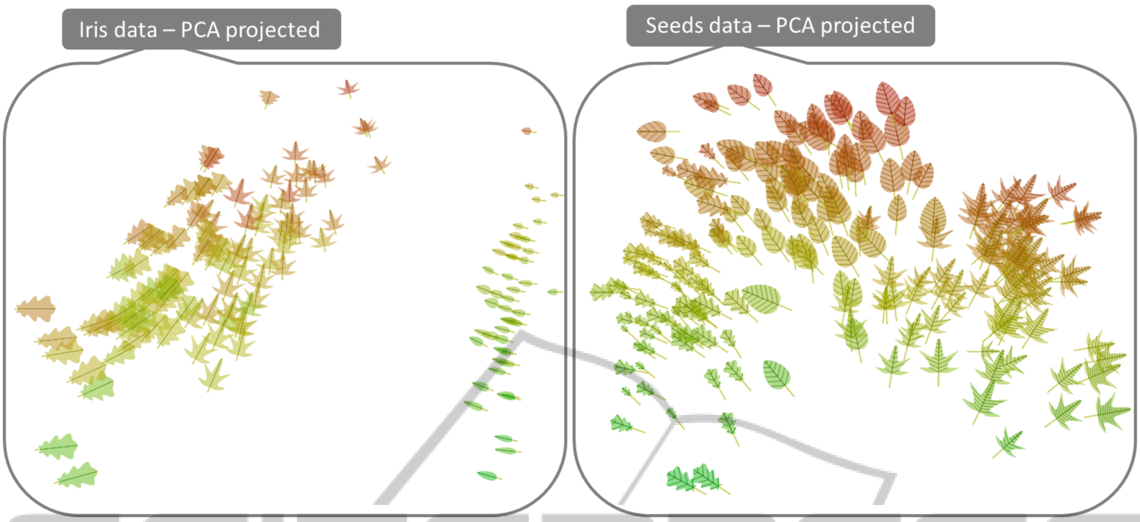

Figure 11: **Infographic Representation:** The well-known iris and seeds data sets from the UCI machine learning repository are visualized using a 2D projection, and an appropriate mapping of data dimensions to leaf shape characteristics.

effective data glyphs, more thorough evaluation is needed. Specifically, we want to compare the leaf glyph against alternative glyphs from the literature, such as Chernoff faces, and pixel-oriented glyphs. This should also include user-studying of effectiveness and efficiency of the technique. We also believe our approach is aesthetically pleasing and may spark interest by a wider audience, for use, e.g., in mass media communication. The leaf glyph may by design, fit well to visualization of environment survey data. Also, this should be evaluated by qualitative consideration.

As a next step, we will combine our multi-dimensional leaf glyph representation with related botanical tree metaphors to extend the design space with a hierarchical layout. We think the combination of the two will support people with no computer science background more easily in understanding complex data structures due to the environmental reference. We further will test this in a controlled environment against more abstract representations such as TreeMaps, etc.

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