



# Glyphs and Visualization of Multivariate Data

Bakkalaureatsarbeit

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#### BAKKALAUREATSARBEIT

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# **1** Introduction

In recent decades the usage of computers has become very common in the industry as well as in research but also in private households. Generally the quantity of data that has to be produced and processed has increased significantly. So it is no surprise that visualization has become a key technology for processing and analyzing large amounts of data. Humans can process visual information much better than text. So it is much easier to get complete insight into an issue if some kind of visual metaphors, that represent the given data, are available. Since computing power is increasing nonstop, new dynamic and interactive visualization methods, which also become more and more complex, are developed constantly.

In this paper I will focus on the visualization of so called multivariate or multidimensional data. Multivariate means that every object possesses more than one parameter and therefore sophisticated visualization techniques are necessary to represent these objects. Since a printed page or a computer screen is limited to two respectively three dimensions new ways of displaying multidimensional objects had to be developed. At first I will discuss three different ways of plotting multivariate data: the Profile Plot, the Andrew's Plot and the Pinion Plot. Then I will take a closer look at glyph based methods for visualization of multivariate data. Since this is the key issue of this paper, this section is going to be the most detailed one.

# 2 Displaying Multivariate Data

Multivariate means that every data object has multiple attributes or parameters. The contrary would be univariate data. Here each object has only one attribute (for example potency of a tablet).

By analyzing multivariate data coherencies among different data objects can be verified or detected. For example heart rate, blood pressure and cholesterol levels of a group of patients in a hospital could be used to determine the risk of some kind of disease.

Nowadays there are many different graphical techniques and computer software packages that are able to display multivariate data. They use combinations of color and shape to visualize all parameters of multidimensional data objects. However, most of these techniques do not transfer well to a printed page and that's also the reason why it is not very common to use such visualizations in reports or research documents [Schwenke and Fergen, 2002]. In the next section I want to discuss four different techniques for displaying multivariate data. Two very common techniques are going to be described: the profile plot and the Andrews plot. Then we will take a shot look at the pinion plot as an alternative to the standard techniques. All of these plots are capable of representing any number of attributes in a two dimensional picture.

# 2.1 Profile Plot / Parallel Coordinates [Rencher, 1995, Inselberg and Dimsdale, 1987]

The profile plot consists of straight horizontal and vertical axes that are orthogonal to each other. In addition there are several equispaced vertical lines along the base of the plot. Each of these lines represents one parameter of a multivariate data set. Obviously the number of parameters than can be visualized is almost unlimited.

A particular data object is represented by a line that connects the vertical spikes at the specific height that yields form their parameter values. This is called the "profile" of an object. Colors or line type of these lines can be used to group objects.

There is a technique that is called *Parallel Coordinates* which is basically the same. The term *Parallel Coordinates* appears pretty often in the context of information visualization, for more information see [Inselberg and Dimsdale, 1987].

Figure 1 shows a data table that was taken from [Rencher, 1995], originally presented by [Kleiner and Hartigan, 1981]. The data are the percentage of republicans votes cast in presidential elections. Data for six southern states was collected from six selected election years. Here, the six southern states represent the sampling units with the six election years representing the response variables. Figure 2 is a profile plot of the data presented in figure 1. The profile plot shows the relationship in voting preference among election years for the various states.

	Year									
<u>State</u>	<u>1932</u>	<u>1936</u>	<u>1940</u>	<u>1960</u>	<u>1964</u>	<u>1968</u>				
Missouri	35	38	48	50	36	45				
Maryland	36	37	41	46	35	42				
Kentucky	40	40	42	54	36	44				
Louisiana	7	11	14	29	57	23				
Mississippi	4	3	4	25	87	14				
South Carolina	2	1	4	49	59	39				

Figure 1: Percentage of people voting republican in presidential elections. [Rencher, 1995]



Figure 2: Profile plot of the table in figure 1. [Schwenke and Fergen, 2002]

#### 2.2 Andrew's Plot [Andrews, 1972]

This technique is named after its originator D. F. Andrews. He proposed to create a function (usually the interval for this function is  $[-\pi, +\pi]$ ) for each data object using the following trigonometric polygon:

 $f(t) = y_1/2^{1/2} + y_2 \sin(t) + y_3 \cos(t) + y_4 \sin(2t) + y_5 \cos(2t) + \dots$ 

This is basically a Fourier transformation where each component represents one parameter of a data set. The values of a specific object are inserted into the  $y_1 - y_n$  variables. The output of this function is a sine-cosine wave that represents one data set. In this technique the arrangement of the parameters does make a difference. The first few variables tend to dominate which means that they have a bigger influence on the appearance of the resulting curve. So if one parameter is for some reason more important than the rest it should be placed

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at the start of the component sequence. This is an unwanted side effect of the Fourier transformation.

An important feature of the Andrew's Plot is that the resulting function preserves the arithmetic means, the variance and the Euclidian distance among the data objects. That means that two objects that have similar parameter values also have very similar resulting curves.

Figure 3 shows an Andrew's plot of the data table in figure 1. It is easy to identify the similarities and differences among the states.



Figure 3: Andrew's plot of the table in figure 12. [Schwenke and Fergen, 2002]

#### 2.3 Pinion Plot [Schwenke and Fergen, 2002]

The Pinion Plot is a technique that reuses the two axes of a normal two dimensional plot to display any number of parameters of a multivariate data set. For example if  $Y_1, Y_2, ..., Y_n$  are the parameters of data set a normal scatter diagram would plot  $Y_1$  versus  $Y_2$ . In the Pinion Plot the axes are reused to plot  $Y_3$  versus  $Y_4$ ,  $Y_5$  versus  $Y_6$  et cetera. This is done until all parameters are represented in the diagram. If there is an odd number of parameters, the final parameter is plotted on one of the axis as an individual variable. At the end all of the points that were generated during the process are connected and represent one specific data object. It is very common to use various symbols to mark which points are connected to which pair of parameters.

The arrangement of the parameters greatly affects the outcome of this technique. If different parameters are paired the output plot will look different as well. In principle the plot is only a "projection" of the multivariate data. So this is a pretty "interactive" technique since the user can experiment with different pairings to optimize the result.



#### 2.4 Summary

The big advantage of all three presented plots is that they make it very easy to compare different data objects. Univariate plots cannot display similarities and differences among different groups/populations of objects as effectively.

All three plots are very often used to find outliners in a group of data objects. An outliner is an extreme or aberrant data value, deemed to be uncharacteristic of the sampled population [Schwenke and Fergen, 2002].

The results for a given group of objects for the Andrew's Plot and the Pinion Plot can be influenced by the user: The order of the parameters in the Andrew's Plot affects the resulting curve and the parameter pairings of the Pinion Plot have a great effect on the result. For the Pinion Plot this "interactivity" can be counted as an advantage because it offers different possibilities to look at the same group of objects whereas the non-uniform influence of the components of the Andrew's Plot is not always a desired feature since quite often the different parameters are equally important.

All three presented types of plots are very well suited for visualizing multivariate data. The quantity of data objects that are displayed simultaneously should not be too large though since all three plots become rather indistinct as the number of visualized objects increases. Thus some glyph based techniques (like *Stick Figures* or *Color Icons* which are able to produce global structures) are the better choice for large amounts of data sets. Furthermore glyphs like *Chernoff faces* for instance are very well suited to identify certain groups of objects with similar parameter values.

# 3 Glyphs

Otto Neurath developed an educating system using pictures [Neurath, 1936]. He suggested employing symbols to illustrate various complex issues, for example occupational categories. The goal was to design the symbols as easily comprehensible as possible in order to avoid the need to look at the legend all the time. Neurath suggested mapping the values of a plot to the number of symbols. This could displace a bar chart for example: The number of symbols would replace the length of a bar and the look of the symbol would replace the labels. This approach can be seen as the forerunner of glyph based visualization.

#### 3.1 What is a glyph?

"A symbolic figure or character, usually a picture, that gives information." [Brooklyn Public Library, 2002]

The word *glyph* originates from the Greek word for a carving. It has two similar but not identical contextual meanings:

#### 3.2 Glyphs in visualization

A glyph is a graphic object or symbol that is used to represent any kind of information. The goal is to encode multiple parameters of a dataset in a single object. That is why glyphs are very often used in connection with information visualization. In some papers the word *icon* is often used as a synonym for *glyph*.

A good example for a simple glyph is an arrow that has a certain length, width, orientation and even color. These four attributes are easy to perceive and can encode four different parameters in one graphic object. This arrow glyph is often used to visualize for instance vector fields.

In this paper the attributes of a glyph (length, form, orientation, color, et cetera) that encode the parameters of a dataset will be called *presentation variables*. The parameter value of such a presentation variable gives information about the value of the according field in the data set. Assigning all parameters to all possible presentation variables is called *mapping*. This is the most important step for the design of a new glyph. Here the range of values for the parameter has to be taken into consideration because not every presentation variable is suited for small respectively big ranges.

The drawback of a visualization using glyphs is that the usage of these objects has to be learned. Therefore a legend that describes the mapping is crucial for every application.

#### 3.3 Glyphs in typography

In typography the graphic form of a symbol is called glyph. The symbol is the abstract form of a letter or of another typographic figure (for example a Chinese symbol). The glyph is the concrete graphic illustration of this symbol. Electronic symbols such as plain text are encoded and stored in bit strings. To display them glyphs are used.

One glyph can be used for multiple symbols. For example on old typewriters the symbols for umlauts where located on an extra key and represented therefore a separate glyph. In connection with the keys for a, o and u the letters ä, ö and ü could be generated.

## 4 Examples

Glyphs are used in many different applications that have visualization of information as a key aspect. A few important examples are being presented in the following section.

#### 4.1 Chernoff faces [Chernoff, 1973]

Chernoff faces are one of the most common type of glyph. They are used to illustrate trends in multidimensional data. Their name comes from Herman Chernoff who designed this glyph in 1973. Here the features of a human face such as position of the eyes, length of the nose or form of the mouth are used as presentation variables. For the mapping the appearance of this glyph as a whole has to be taken into consideration because the various presentation variables have dissimilar influence on the overall appearance. This overall look of a Chernoff face comes to the fore particularly because as humans we can perceive and classify a face very quickly.

Figure 5 shows an example for a Chernoff face visualization. These faces were created by analyzing a statistic census about the contentedness of patients in a hospital with the provided care [VGSPS, 2000]. The meaning of each facial feature can be found in the legend in the bottom right of the figure. Each face stands for the contentedness of one patient.



Figure 5: Contenteness of patients of a hospital. [VGSPS, 2000]

When using Chernoff faces it has to be taken into consideration that a human face can be interpreted very differently among multiple observers. Furthermore it is possible that personal preferences regarding facial features prohibit an objective apperception of the available information. That is also the reason why specific data values cannot be identified – they can only be estimated.

Another disadvantage of the Chernoff faces is that a legend to describe the mapping is always mandatory and so the usage of the glyphs has to be learned. Furthermore this kind of glyph does not qualify for the visualization of very big data pool because it does not generate any kind of global texture. For this manner Stick Figures or Color Icons are the better choice (see section 4.2 and 4.4 for more details).

Chernoff faces are a very good method to discover maxima and minima of a database. Exceptional parameter values can be identified pretty easily because the accordant facial feature should look very eye-catching.

#### 4.2 Stick Figures [Picket and Grinstein, 1988]

Another possibility to illustrate multidimensional data is a type of glyph that is called Stick Figure. Basically it consists of different types of lines. A stick figure has one main axis whose orientation and alignment already encodes two parameters. More lines can be attached to the main axis and in this way a bigger stick figure is generated. So the presentation variables of a stick figure are form and orientation of the different lines. Their color, width and height et cetera can vary and in this way visualize additional attributes of the data set. When the number of attributes increases stick figures become pretty complicated and overloaded. That's why in reality the number of attributes that can be illustrated is limited to just a few. An advantage of stick figures is that they produce global textures when available in large quantities. If that is the case it is pretty easy to identify global structures or patters within the data.





Figure 7: Stick figures used to visualize temperature and height data of the mars. [Müller, 2004]

#### 4.3 Autoglyph [Beddow, 1990]

This technique – sometimes it is also called *Shape Coding* – uses an axially parallel rectangle to encode a data set. This rectangle has a lattice-like structure where every cell of the grid is assigned to one attribute of the data set (see figure 8). To encode the value of an attribute the color of the according cell is used. To be able to differentiate between the various values, autoglyphs should only be used for nominal attributes with small value-ranges. They are very well suited especially for binary attributes. Glyphs of different data sets can be arranged in any order but mostly this is done line-by-line.

Their compact form is one of the main advantages of autoglyphs. They were created to illustrate the correlation among a big quantity of data sets. Consequently the biggest drawback of this technique becomes clear: The identification of a single data set in a big field of glyphs is very difficult. It also requires a significant amount of time to study an autoglyph.



Figure 8: The lattice-like structure of an autoglyph. [Krömker, 2001]

	Q	1	S	3	4	1	6	2	Б	2	10	11	12	17	11
0	2		-	12		12	-	-			-	-21			17
15	8	Π.		-				125	12	1.	<b>T</b> .		12	12.5	
30	95.	2.1	-	-		12	-		-						
45					1			10				-	-	-	
50					212			12			-			14	
15						100	-	-			12.5	-		-	12.
30					100			12.		-					12.
05			1	17 J							e.,		-		
20	P								_		-		<b>P</b> .		нe.,
135		2							1	100		100			
50						-	1.0	100			1				
111		-				11				E.	_		-		U.,
00	24		ш		101	1			-		1		-		1
	<b>1</b>			-				00.	-	10.1			-		10

Figure 9: Microbiologic data encoded in autoglyph; There are 8 different attributes for resistance and 210 glyphs each for one person. [Krömker, 2001]

#### 4.4 Color Icons [Levkowitz, 1991], [Erbacher et al., 1995]

This technique was developed by Haim Levkowitz. Here an area – in most cases a square – is divided into multiple sub areas. The term *patch* is often used for the polygon that defines the outer hull of the glyph. Different colors are assigned to each sub area. Each parameter of the data set is attached to one sub area and the hue of the according color represents the value of the parameter. This approach provides better parameter separation since the sub areas look more outlined. By highlighting specific edges it is possible to accentuate a certain group of parameters.

Another possibility to create a Color Icon would be to color the edges and to interpolate the area in between. This approach provides better parameter blending. Here the parameter values seem to merge slightly.

The form of the patch is not determined to a square. Hexagons or other periodic polygons can be used to increase the number of visualized parameters. Thus it is also possible use the form of the patch to encode one parameter. This could make it easier for the viewer to recognize patters in the output diagram and therefore the global distribution of the data could be discovered.

The number of parameters that can by visualized by a Color Icon is limited because more than 8 sub-areas would overload a quadratic patch. A possibility to counteract this problem is allowing three dimensional patches and therefore rendering more parameters possible. A height that represents one parameter would be assigned to each vertex of the patch. The rendering of such three dimensional Color Icons requires much computing power and that's why they aren't used very often.



Figure 10: Color Icon. [Krömker, 2001]



Figure 11: Color Icons are used to visualize a homicide-database from the FBI. [Erbacher et al., 1995]

#### 4.5 The VIE-VISU System [Horn et al., 1998]

In the VIE-VISU system glyphs are used to represent changes of data values over time. They often resemble the frames of a movie: the same graphical object changes its shape and color from frame to frame. The time steps between frames are fixed as is the basic design of the frame. The fixed design focuses attention to the shifts of the data over time. In this context the expression "metaphor graphic" often appears. It is basically a synonym for glyph. The word *metaphor* refers to the fact that the appearance of a metaphor graphic as a whole is here very often related to the context of data that is visualized. In the VIE-VISU system for instance the form of each glyph is intended to resemble a human body.

VIE-VISU is used to visualize the medical data of a neonatal and its changes over time. Breath rates and breath volumes for instance are sketched by the size and volume of rectangles. The actual value of a parameter is either depicted by the size of an object or by its color.

These metaphor graphics are well suited to reveal repetition and change, enabling the user to identify patterns. The 24 hours display of the VIE-VISU system (see figure 12) enables the physician to comprehend the current situation and find critical spots in patient care very quickly.



Figure 12: 24 hours display of the VIE-VISU system. [Horn et al., 1998]

#### 4.6 Mosaic Metaphors [Nocke et al., 2005]

Another type of metaphor graphics are mosaic metaphors. In this technique each glyph represents multiple parameters and all of them are arranged on a grid. All the objects combined generate a specific shape that is somehow linked to the content of the data, for example the form of a state. You can see an example for a mosaic metaphor in figure 13. It shows data about the cultivation of corn in Brazil.



Figure 13: A mosaic metaphor used to visualize data about the cultivation of corn in Brazil. [Nocke et al., 2005]

#### 4.7 Circle arrangement and Data Jacks [Krömker, 2001]

A very simple approach to visualize multidimensional data is a circle glyph. Here data values are encoded in size and color of circles. Obviously the number of parameters that can be visualized is very limited. The horizontal and vertical position of each circle can be used to encode two parameters but this type of glyph is still only suited for small data sets. Another rather simple type of glyph are Data Jacks. Data values are encoded in the length and color of four limbs which are attached to a rectangle. Data Jacks have much more presentation variables than circle arrangements and therefore are more flexible and useful. Sometimes they are used as Moving Icons to minimize occlusion effects.





Figure 14: Circle arrangement. [Krömker, 2001]

Figure 15: Data Jack. [Krömker, 2001]

# **5** Conclusion

As mentioned before the importance of information visualization for multivariate data has grows significantly in recent years. As new technologies appeared the amount of existent data constantly increases and therefore new methods become necessary to be able to analyze, process and finally use all the available information reasonably.

The possible applications for information visualization vary from statistical analysis (for example about the results of political elections as mentioned in section 2) over astronomy (for example figure 7) to biology and medicine. Applications like the VIE-VISU system (section 4.5) for example help physicians significantly with the analysis of a particular patient's data. The possibilities for new applications are almost unlimited.

Glyph based strategies are employed very often for information visualization of multidimensional data. The number of parameters that can be displayed is quite high but also depends on the used technique. A big advantage of glyphs is that they can be positioned in two- or three dimensional space and that a single object is often very compact and therefore can be displayed in a small area.

Glyphs like Color Icons or Stick Figures are able to produce global textures when available in large quantities. But the identification of parameter values for a particular data object is often difficult or sometimes even impossible. These glyphs were designed to identify patterns or trends among many data objects. Also the distribution of certain parameters for example can be found out more easily.

The main disadvantage in using glyphs is that it is mostly impossible to identify the parameter values for a particular data object. That's why it is not recommended to use glyph based strategies as the only decision guidance. There are many other visualization techniques, (for example plots as described in section 2) which can be used in addition, in order to optimize the decision-making process.

Another problem that glyphs have is that their usage has to be learned in most cases and therefore also the process of analyzing the represented data needs training. Thus a legend that describes the mapping is almost always necessary.

The design of an effective glyph requires a pretty big amount of creativity since a bad mapping entails a greater training effort for the final user. So-called glyph editors exist which can aid the designer of a glyph. *Glyphmaker* for example enables the user to create bindings between presentation variables and data attrubites, bring in new data or glyphs with associated bindings, change ranges for bound data, and do these operations interactively [Ribarsky et al., 1994]. There are some more similar applications like *PGO Editor* (see Mulder, 1995]) but none of these tools can guarantee that the resulting glyph representation is going to be "good", meaning that the mapping is intuitive and easy to learn, the appearance of the glyph as a whole has some contextual meaning, the number of parameters that can be visualized is high and the glyph produces some global texture that can be interpreted. So the designer still has to do much thinking in order to create a glyph representation that suits any given requirements.

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