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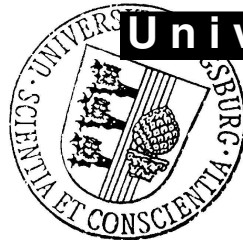
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**Interactive Visualization of Assessment Data: The Software Package
Mondrian**

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Interactive visualization of assessment data: The software package Mondrian

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Abstract

Mondrian is state-of-the-art statistical data visualization software featuring modern interactive visualization techniques for a wide range of data types. This paper reviews the capabilities, functionality, and interactive properties of this software package. Key features of Mondrian are illustrated with data from the Programme for International Student Assessment (PISA) and for item analysis applications.

Keywords: Mondrian; R; Data visualization software; Interactive graphics; Spineplot; Item analysis; Empirical Item Response Function; Distractor Analysis; Differential Item Functioning; Programme for International Student Assessment (PISA) data

Introduction

Data visualization is a vital tool in decision support. Graphics are widely used in modern applied statistics, because they are easy to create, convenient to use, and they can present information effectively (e.g., Cook & Swayne, 2007; Unwin, Theus, & Hofmann, 2006; Wilkinson, 2005; Young, Valero-Mora, & Friendly, 2006). Visualizations, however, are often static (e.g., Emerson, 1998), merely utilized for the presentation rather than the exploration of data. Interactive statistical data visualization, on the other hand, is a powerful alternative for the detection of structural patterns and regularities in the data. Interactive graphics become indispensable especially when analyzing large and complex data sets, in which case statistical modeling and methodologies, generally, fail to account for the complexity of the data satisfactorily (e.g., Unwin, Volinsky, & Winkler, 2003).

This review evaluates Mondrian, a state-of-the-art, interactive data visualization software developed by Theus (2002a, 2002b). A forthcoming book by Theus and Urbanek (2008) thoroughly discusses applications of the software Mondrian to a number of real data examples. Mondrian is a stand-alone package with a wide range of graphics and interactive features, and has been developed in the programming language Java. It is platform independent and is freely available for Windows, Mac OS X, and UNIX, by download from Mondrian's web sites at <http://www.rosuda.org/Mondrian/> or <http://mondrian.theusrus.de/>. These web sites in particular contain a tutorial and sample data sets that can be loaded and tested with Mondrian. (Whereas on Mac OS X a suitable Java virtual machine will be pre-installed, Windows users may have to install a recent Java runtime environment from Sun Microsystems at <http://www.sun.com/>, if not already installed. On UNIX one needs to download the jar-file of Mondrian, and start it manually using the command `mymachine> java -jar Mondrian.jar`.)

Data management capabilities

Mondrian in principle has no practical limitations on the size of data sets that can be managed. The software can load and export data in local tab-delimited ASCII files and also connect directly to distributed or online databases via the JDBC interface. Another useful feature of Mondrian is the simplicity with which it allows to generate new variables from the initial ones of the loaded data set, (a) by calculating functions of selected variables (such as the sum or ratio of two variables, or the logarithm of a variable), or (b) by deriving variables from selections or color assignments.

Plotting capabilities

Mondrian implements interactive graphics for a wide range of data types including missing value plots, and plots for:¹

(a) categorical data: (weighted) barcharts and spineplots (Hummel, 1996), (weighted) mosaic plots and their variations ‘same bin size’ (each cell is allocated the same amount of space, and the information is reduced to the binary case of whether a cell is or is not empty), ‘fluctuation diagram’ (each cell is allocated the same amount of space, and the cell with the maximum frequency fills its space completely, thus fixing the scale for the rest of the diagram), and ‘multiple barchart’ (each cell is allocated the same amount of space, and only the heights of the bars in the cells are scaled) (Friendly, 1994; Hartigan & Kleiner, 1981; Hofmann, 1998, 2000, 2007), and double decker plots (instead of alternately splitting the x and y axes as in a mosaic plot, only the x axis is used) (Hofmann, 2007; Hofmann & Wilhelm, 2001);

¹ Some of the following plot types are shown in the figures that we present. There are examples of a choropleth map, mosaic plot, parallel coordinate plot, histogram, scatterplot, barchart, parallel boxplot, and spineplot in Figure 1, in respective order, top down from left to right. Examples of barcharts and spineplots can also be found in Figures 2-4. Throughout this review, special care is taken to provide a comprehensive list of references for detailed information and further reading on the concepts and issues that we mention or discuss.

(b) continuous data: (weighted) histograms and spinograms (all bars are normalized to have the same height, with proportional widths) (cf. Hofmann & Theus, under revision), scatterplots and scatterplot matrices, parallel coordinate plots (Inselberg, 1985, 1998; Wegman, 1990), parallel boxplots, and boxplots y by x ;

(c) geographical data: choropleth maps (maps with color-shadings to represent quantities) (Carr, Olsen, Courbois, Pierson, & Carr, 1998; Carr, Zhang, & Li, 2002; Dykes, MacEachren, & Kraak, 2005).

All types of plots can handle missing values (coded as NA in the input file). Missing data can even be included as a separate group. For example, when plotting categorical data, missing values constitute an extra group, and the associated plot object is colored white.

Figure 1 provides a gallery screenshot from Mondrian that illustrates some of the aforementioned plot types.²

[Insert Fig. 1 about here]

Mondrian can fully interact with the R statistical computing environment (R Development Core Team, 2006; <http://www.r-project.org/>) to enhance data analysis with statistical procedures.³ This interaction between Mondrian and R provides additional plotting capabilities including: (a) density estimation; (b) smoothing using R functions such as `loess()` and regression splines with confidence intervals; (c) multidimensional scaling; and (d) principal component analysis.

Mondrian also includes a model navigator for the stepwise graphical building of loglinear models using mosaic plots (Theus & Lauer, 1999). Table 1 summarizes key features of Mondrian.

[Insert Table 1 about here]

² For black and white reproduction all figures in this review are presented in gray scales only.

³ Requires connection to Rserve, a freely accessible TCP/IP server.

Interactivity

Mondrian replicates many of the same types of plots readily available in most statistical software packages (e.g., bar charts, histograms, and scatterplots). However, Mondrian is highly interactive and offers a wide range of query and data exploration options. All plots can handle large data sets and are fully linked.

Special features include a binned mode for scatterplots (the plotting region is divided into a regular grid, and the data points falling into a particular bin are aggregated in that bin) and α -channel transparency (also called α -blending) of plotted objects (specifying the transparency of the color of a plotted object) (e.g., Theus & Urbanek, 2008; Unwin et al., 2006). These features avoid overplotting redundant or high-density information that would ordinarily make difficult or even impossible the interpretation of the plots with large data sets.

Linking of plots is easily accomplished by selection, specifying selection sequences, and by highlighting. For example, a single data point or case selected in one plot is highlighted in all other plots. A special characteristic of Mondrian is the provision of selection sequences allowing for step-by-step refined selections of specific parts of the data, which becomes indispensable especially when dealing with massive data sets (Theus, Hofmann, & Wilhelm, 1998; see also Schneiderman, 1994; Wills, 1996). Selection sequences allow users to combine current selections with new selections via simple Boolean operators. By storing the sequence, it is possible to flexibly modify any individual selection in the sequence during data analysis.

Creating multiple (simultaneous) views in single or different plot windows, manually and automatically sorting and reordering categories and variables, and varying point size of points in a scatterplot are further interactive options available in Mondrian. Mondrian

also allows for standard, logical, and censored zooming, and color brushing (persistent assignment of colors; for instance, to mark outliers more permanently).

Mondrian's help system includes a reference card that summaries all keyboard and mouse shortcuts, for the Windows and Mac OS X operating systems; for instance, including information on how to export graphics. However, the reference card is not mature, for instance not allowing for changing the size, copying parts, or even adding new entries.

Sample graphics and applications⁴

Some of the key features of Mondrian are next illustrated with part of empirical data from the 2003 Programme for International Student Assessment (PISA; <http://www.pisa.oecd.org>) using two data sets with multiple-choice or open format test data (available from the authors). One data set contains item responses by 317 German students on a 12-item dichotomously scored, mathematical literacy test. This data set also included a sex variable coded as 1 = female or 2 = male. The other data set contains item responses by another set of 327 German students on another 5-item polytomously scored, mathematical literacy test.

An interesting application of Mondrian might be to conduct a visual item analysis. For example, Figure 2 shows side-by-side spineplots (upper plots) for two items (Items 6 and 7 of the first data set) where the proportions of correct responses (horizontal axes) are plotted as a function of the number-correct (total) scores (vertical axes). The marginal absolute correct and incorrect values are displayed as barcharts below the spineplots. This type of depiction provides an empirical item response function plot and also suggests a positive linear relationship between the conditional correct item response proportions and the total scores. This type of plot could be supplemented with a smoothing function, if desired.

⁴ This section has greatly benefited from comments made by Professor Richard M. Luecht.

[Insert Fig. 2 about here]

Figure 3 provides a corresponding visual ‘distractor analysis’ that shows the proportions of examinees responding to each response category for two items (Items 1 and 3 of the second data set), with the proportions again conditional on number-correct (total) score. This type of visual analysis might detect particular *incorrect* distractors that are proportionally more attractive for examinees within particular regions of the total score scale.

[Insert Fig. 3 about here]

Figure 4 displays the separate proportion-correct bars for one item (Item 4 of the first data set) as a function of the total score for males and females. This type of graphic provides a crude visual analysis of differential item functioning or DIF (e.g., Holland and Wainer, 1993). In this type of plot, we do not get an aggregate measure of DIF, but perhaps a better indication of where along the total score scale, if anyplace, the two sex groups, matched on total score, differ in their apparent response to a particular item. This example does not imply that Mondrian would replace conventional DIF analyses, however, it could certainly supplement the information provided to test developers or item editors for items flagged as demonstrating significant DIF.

[Insert Fig. 4 about here]

Conclusions

This review is intended to inform and encourage people working in such disciplines as psychometrics and, even broader, quantitative psychology, to take advantage of the most current techniques in the field of interactive graphics. As illustrated by the exemplar graphics of assessment data, the latter can provide a way of better understanding the data and

supporting the process of model building, which shall be a useful supplement to the applied work of a variety of measurement professionals and researchers.

Mondrian can do quite well, in this respect. Different views demonstrated by graphics implemented in Mondrian help users to interactively and flexibly see, with relatively low investment of time to become proficient, particular aspects of their data. Besides being available for free, the software package Mondrian is constantly updated to cover recent developments in the research on interactive graphics. It is intuitive and easy to use, and features many powerful capabilities for the efficient analysis of (even very large) data.

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We thank Professor Antony R. Unwin for introducing us to interactive graphics and the software Mondrian, for motivating us to write this review, and for his helpful comments on a first draft of the manuscript. Thanks are also given to Martin Theus for his invaluable expertise and help that he provided us, and to Waqas Ahmed Malik for fruitful discussions about Mondrian. We are grateful to Professor Mark L. Davison, Editor in Chief, for his work on this review. In particular, we are deeply indebted to Professor Richard M. Luecht, Computer Software Review Editor. His critical and valuable comments and suggestions have improved the manuscript greatly.

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Figure captions and notes

Fig. 1. Gallery Screenshot from Mondrian

Note. Data on the 2004 United States presidential election, which for instance can be downloaded from Mondrian's web sites, are used to produce the individual plots.

Fig. 2. Empirical Item Response Functions: Barcharts for Items 6 and 7 (Lower Plots) and Corresponding Spineplots for the Total Score (Upper Plots)

Note. In the barcharts the examinees solving that particular item are color brushed. In the spineplots the proportions of correct responses are plotted as a function of the number-correct (total) scores.

Fig. 3. Distractor Analysis: Barcharts for Items 1 and 3 (Lower Plots) and Corresponding Spineplots for the Total Score (Upper Plots)

Note. In the barcharts the examinees responding to a particular category of the items are color brushed. The proportions of examinees responding to each response category, conditional on total score, are depicted in the spineplots.

Fig. 4. Differential Item Functioning: Barcharts for Item 4 (Lower Plots) and Sex (Middle Plots) and Corresponding Spineplots for the Total Score (Upper Plots)

Note. In the lower barcharts the males and females solving that item are color brushed. Their fractions of the total number of males and females are depicted in the middle plots. The spineplots display the separate proportion-correct bars as a function of the total score for males and females.

Figures

Fig. 1

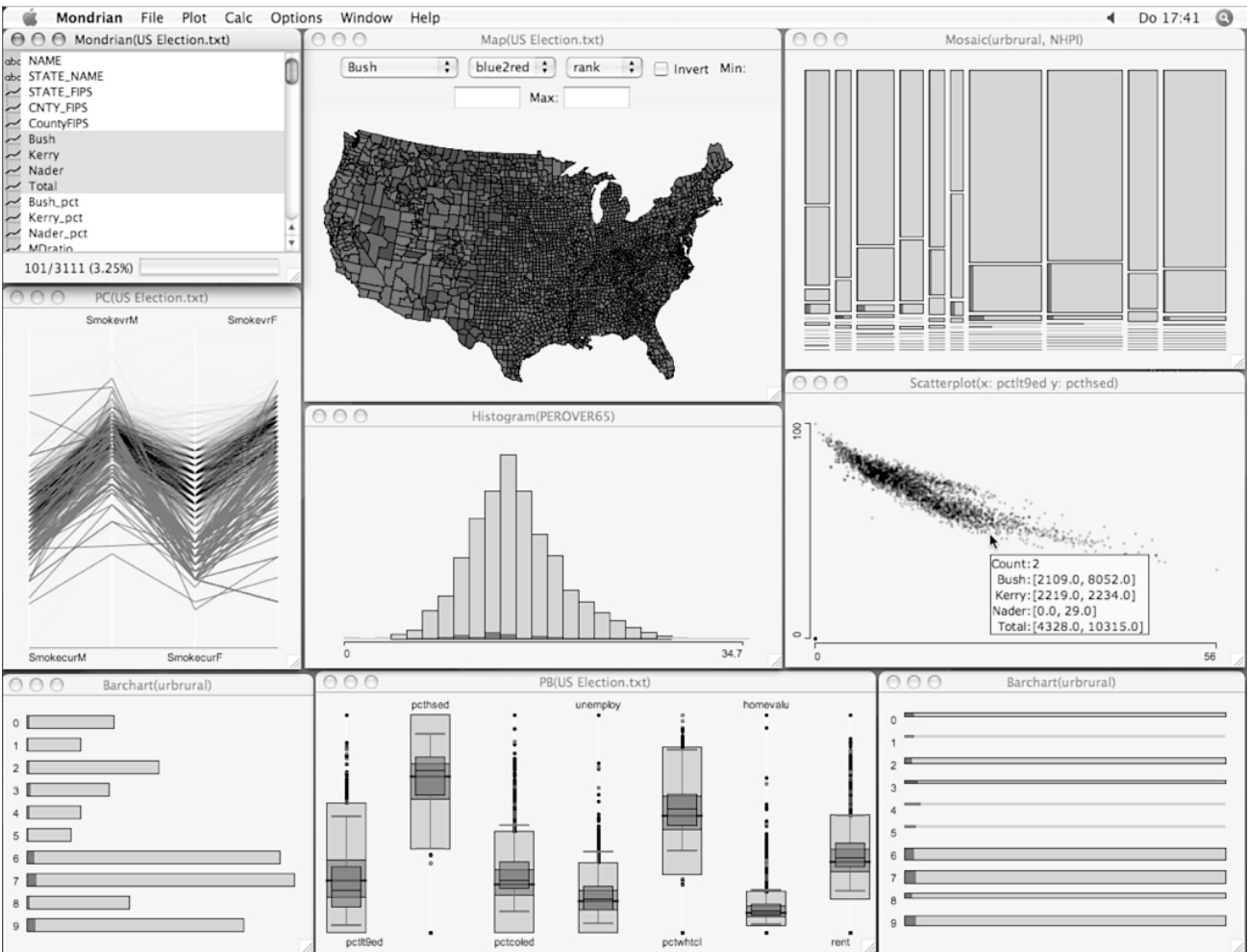


Fig. 2

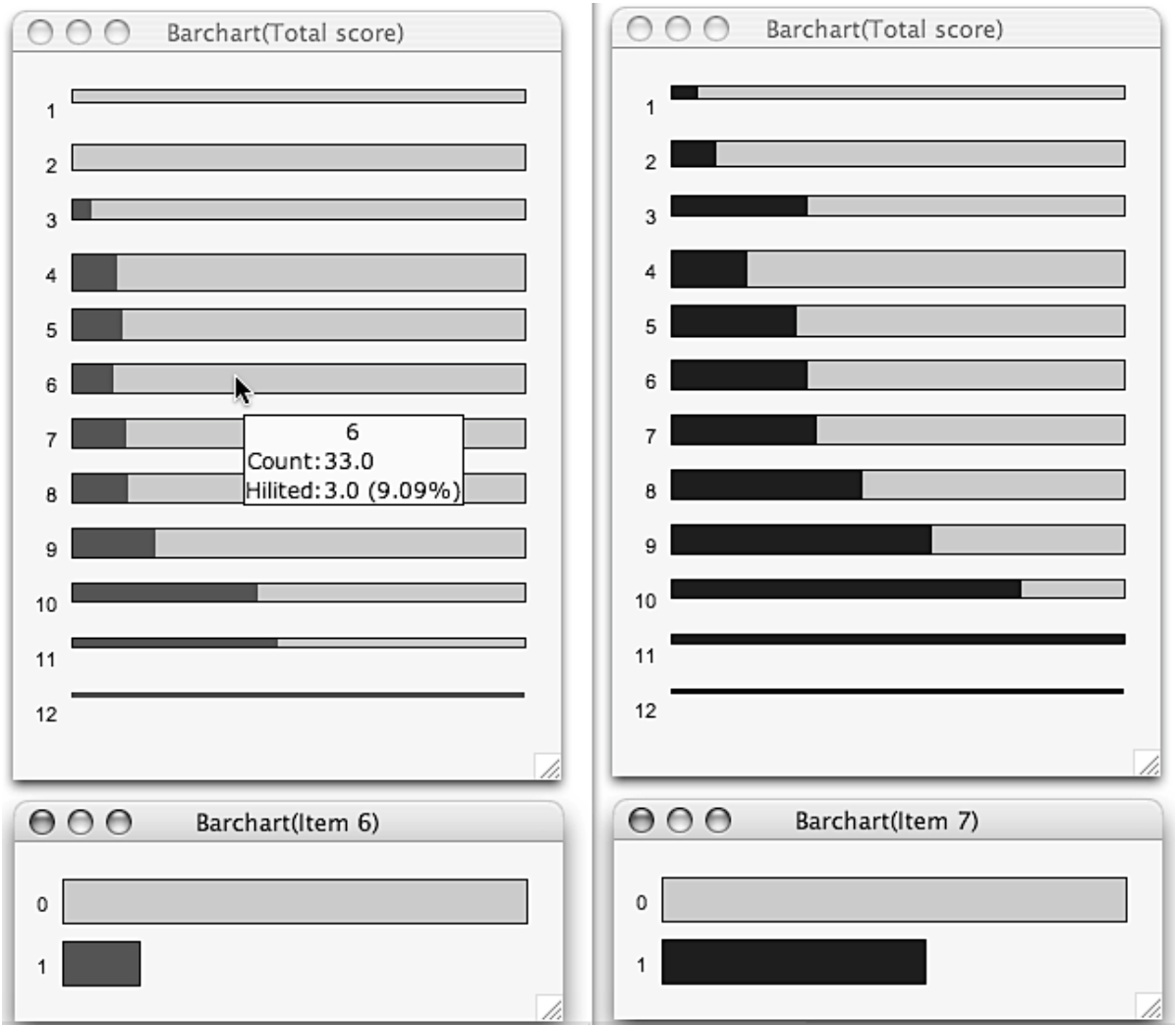


Fig. 3

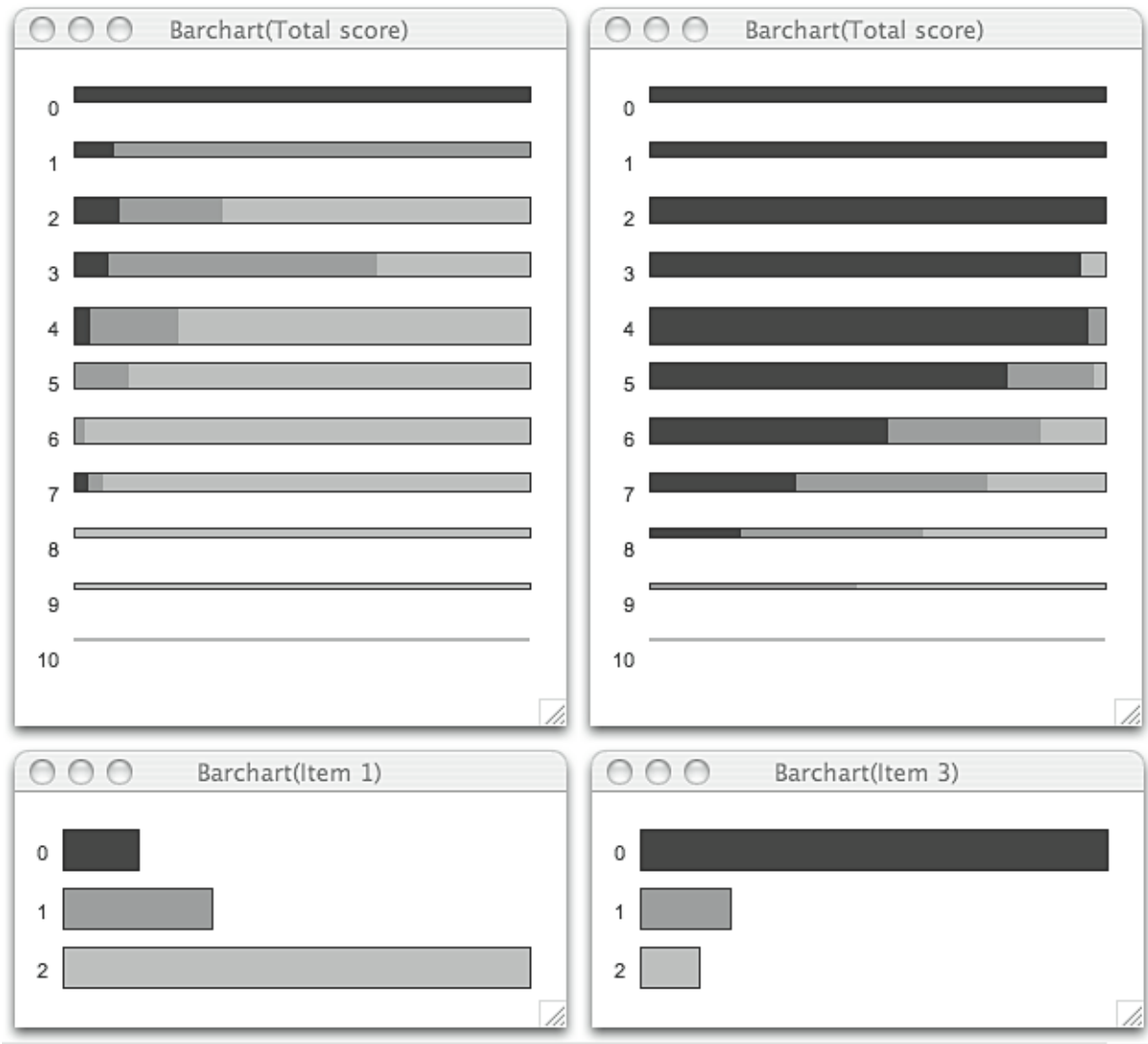


Fig. 4



Table 1

Key Features of Mondrian

Plot	Data type	R functionality	Plot variation	Interactivity				
				Linking	Querying	Zooming	α blending	Binned mode
Missing value plot	Categorical, continuous	—	—	Available	Standard	Standard	—	—
Barchart	Categorical	—	Weighted barchart, spineplot	Available	Standard	Standard	—	—
Mosaic plot	Categorical	—	Fluctuation diagram, multiple barchart, same bin size, double decker plot	Available	Standard	Standard, censored	—	—
Histogram	Continuous	Density estimation	Weighted histogram, spinogram	Available	Orientation, standard	Standard	—	—
Scatterplot	Continuous	Smoothing: least square, loess, splines	Scatterplot matrix	Available	Orientation, standard, extended	Standard, logical	Available	Available
Parallel coordinate plot	Continuous	—	Parallel boxplot	Available	Standard, Extended	Standard	Available	—

Note. Other plots implemented in Mondrian are boxplots y by x and choropleth maps. All plots can handle missing values and are fully linked. Linking of plots is realized via selections, selection sequences, and highlighting. Mondrian also allows for the interactive options of creating multiple (simultaneous) views in single or different plot windows, manually and automatically sorting and reordering categories and variables, color brushing, and point size variation of points in a scatterplot. Further R functionalities of Mondrian (R computations callable in Mondrian) are multidimensional scaling and principal component analysis. Mondrian includes a model navigator for the graphical building of loglinear models using mosaic plots. Eventually, new variables can be generated from the initial ones given in the loaded data set. (Orientation querying: gives the location of the mouse pointer in the coordinate system of a plot; standard querying: gives basic information associated with an object of a plot; extended querying: gives additional information, not only related to the variables used in a plot, but to other information about an object of the plot. Standard

zooming: the display is magnified; logical zooming: as magnification increases, more detail is shown; censored zooming: in ceiling-censored zooming objects are magnified up to a limit, in floor-censored zooming objects smaller than a size are not displayed.)