

# Visually Augmenting Documents with Data



Shahid Latif\*


Fabian Beck†

paluno – The Ruhr Institute for Software Technology  
University of Duisburg-Essen, Germany

## 1 INTRODUCTION

“A picture is worth a thousand words” is a famous English saying. It is true in many cases, because a complex idea or data can be simply conveyed through the use of a single static image or diagram. Therefore, inclusion of graphics and visualizations in scientific texts has been an important aspect ever since researchers started publishing articles. Conventional writing styles allow researchers to provide images, graphs, and tables to enhance the readability and understandability of text. But usually, these large-scale images need to be placed at a slightly different location from the relevant text, either on the same page or on the next pages. This far-off placement of graphics forces the readers to switch their attention between text and graphics, which can cause a split-attention effect [1], thereby increasing the cognitive effort to comprehend the information.

Hence, integration of text and images next to each other—without disturbing the flow of text—can help avoid the split-attention effect and reduce cognitive load. In contrast to large visualizations, word-sized graphics are visualizations produced at the height of a text line and about the width of a word. They can be completely embedded within the lines of text allowing the reader to remain focused on the same spatial area. Figure 1 illustrates how the use of word-sized graphics (e.g., , ) integrated within a text or table can reduce the split-attention effect by presenting most of the visualizations next to the relevant text. In a table, word-sized visualizations can provide visual comparison of information by placing multiple instances next to each other.

Tufte [13] introduced the term *sparkline* as “*data-intense design-simple, word-sized graphics*”. For instance, fluctuations in EUR–USD currency exchange rates (2012–2016) can be easily seen in a word-sized line chart   $1.6$  <sub>$1.0$</sub> . The use of *sparklines* has become increasingly popular during the past decade and they are widely adopted in many interactive dashboards and spreadsheet applications. Also, they have already been used in scientific publications to communicate data [3]. *Sparklines* can be misunderstood to only refer to line charts but, in general, they can represent any type of graphic, e.g., bar charts, scatter plots, box plots, or even node-link diagrams. Throughout the rest of the paper, we use the term *word-sized graphics* to refer to the above-mentioned definition of data-driven graphics by Tufte. Other common terms for the same or similar concepts are *word-scale graphics/visualizations* or (*visual*) *glyphs*.

This work explores the potential of augmenting scientific texts with word-sized graphics for communicating scientific and engineering data. We focus on how to produce, use, and coherently embed word-sized graphics in text and tables. Various possibilities of using word-sized graphics for temporal, multivariate, spatial, and relational data are discussed. We demonstrate the usefulness




and full potential of word-sized graphics by showcasing an application example for analyzing eye tracking data. We finally reflect design criteria for the graphics and their embedding as well as discuss aspects of application in practice. With that, we hope to foster a discussion of how data can be best represented in publications to communicate measurements and simulations results.


## 2 REPRESENTING DATA WITH WORD-SIZED GRAPHICS

Although word-sized graphics have been widely discussed in literature, integration of these small visualizations in scientific publications is still scarce. Beck and Weiskopf [3] present a survey of actual use of data-driven word-sized graphics in publications. The literature collection, with the possibility to filter publications on the basis of keywords, is available online.<sup>1</sup> Interested readers can explore the state of the art regarding applications of word-sized graphics in computer science and engineering (tagged as *domain:engineering* in the afore-mentioned literature collection). In most of the existing papers published in the engineering domain, the use of word-sized graphics is restricted to simple line charts with very few exceptions (Hlawatasch et al. [9] visualize trajectories). Also, the existing publications introduce word-sized graphics just as examples or use them to augment other visualizations (e.g., [5]). We argue that word-sized graphics are much more flexible with respect to the type of visualization shown. In contrast to existing work, we explore and advocate the use of word-sized graphics as an integral part of publications, communicating measurements or simulation data embedded into the text of the publication or as small multiples in tables and lists.

One might expect that the flexibility of word-sized graphics is very limited because of their small scale. However, limitations are surprisingly little and quite complex data is representable. Word-sized graphics can be used for numerous data types and are universally applicable to univariate, multivariate, spatial, and relational data. This section discusses basic options for representing different data types as word-sized graphics; Table 1 provides an overview and summary. This design space of data-driven word-sized graphics is derived and abstracted from existing collections of word-sized graphics [3, 6].

### 2.1 Univariate Data

One of the simplest forms of visualizing a value of a single variable is a bar encoding the value as width . Common variants are representing the value as height, area, or color. For integer values, also the discrete items can be listed . Visualization, however, becomes more relevant when multiple values of the same variable are involved. For instance, proportional division of a whole might be visualized as a subdivided area ; pie charts are the radial version of this.

Further, time series data is a common type of data to be conveyed through the use of word-sized line charts and bar charts. Line charts  typically indicate continuous phenomena, where interpolation between points in time is valid. The practical use of line plots as word-sized graphics can be seen in the work of Dutta and

\*e-mail: shahid.latif@paluno.uni-due.de

†e-mail: fabian.beck@paluno.uni-due.de

<sup>1</sup><http://sparklines-literature.fbeck.com/>

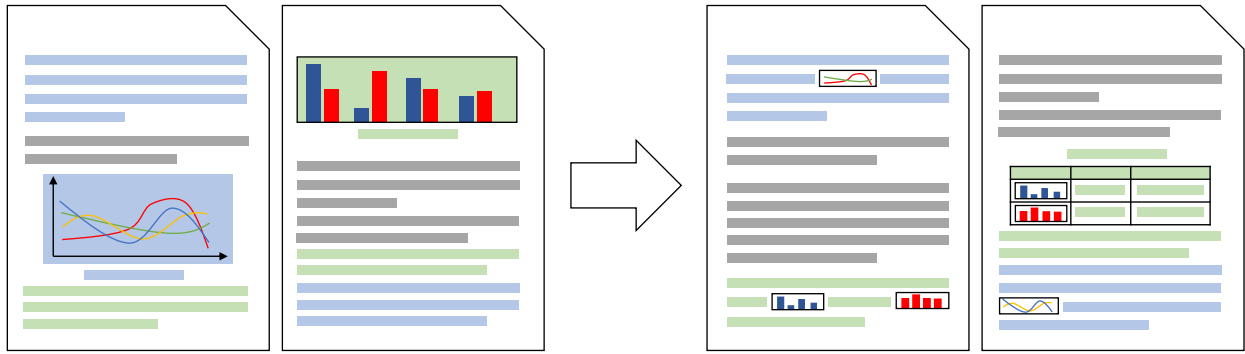

















Figure 1: (Left) Document without word-sized graphics where the reader has to switch attention between graphics and text. (Right) Document using integrated word-sized graphics in line with the text and in tables to reduce a split-attention effect and save space for additional content (here, a table with further information). Colors ■ indicate the textual and visual content that relate to each other.

Overbye [5], which analyzes time-varying data of wide-area power systems and demonstrates the results via word-sized graphics as an augmentation to a geographical overlay. Area charts  with a filled area below the line highlight that there is an interpretable baseline or absolute amount. Function plots  ( $\text{sinc}(x)$ ) are another variant of a line plot; they might show a function of time, space, or any other continuous dimension. Bar charts , in contrast, focus on discrete instances and have an interpretable baseline like area charts. Bar charts can be used for time series, but are as well suited for comparing values of different items. A frequent application of bar charts is histograms, which bin items with respect to their variable value and show frequencies per bin as bars. Simple bar and line charts can be enriched with further information, for instance, to indicate minimum and maximum values  . If we just want to indicate whether something is active across time, a simple timeline diagram  marking activity phases is another visualization of evolving univariate data.

## 2.2 Multivariate Data

For comparing multiple variables, we might extend univariate visualizations by adding another overlay or integrating another data column. In its simplest form, a bar chart  can also be considered—instead of a univariate comparison of items—a comparison of multiple variables for a single item. Line charts represent multiple variables when adding further lines as overlay  and (univariate) bar charts when splitting each bar into a sequence of bars . A visual table  instead lists the variables and items in a grid structure with variable values encoded as colors. Timeline diagrams with separate rows  compare the occurrence and length of distinct types of events. *Gantt charts*, a common diagram type used for project planning and management, can be considered as a variant of this.

Statistical diagrams can also be used for comparing multivariate variables and scale to more items. Box plots  aggregate the items and describe the central tendency, variability, and outliers. Two variables can be compared using scatter plots , which can be extended to bubble charts  to show a third variable in dot size. For comparing more variables, parallel coordinates  encode the dimensions as parallel vertical axes with lines indicating the items.

## 2.3 Spatial Data
























Spatial data contains coordinates in two- or three-dimensional space. Geographic data is a special form that can be represented as a map. Simple data such as points can be overlaid on a map  (this example shows the location of the three biggest cities in the US). Choropleth maps  display quantities per region encoded in the color or shade of the region. In contrast, heatmaps 

Table 1: Basic word-sized graphics.

Visualization	Data
<b>Univariate Data</b>	
	Quantity
	Subdivided area
	Line chart
	Bar chart
	Timeline
<b>Multivariate Data</b>	
	Line comparison
	Bar comparison
	Table
	Timeline comparison
	Box plot
	Scatter plot
	Parallel coordinates
<b>Spatial Data</b>	
	Map
	Heatmap
	Trajectories
<b>Relational Data</b>	
	Node-link
	Adjacency matrix
	Geographic location or region
	Spatial scalar field (2D density)
	Spatiotemporal
	Relational (network), hierarchical (tree)
	Relational (network)

do not discern between geographic boundaries but use a regular grid. Trajectory data corresponds to the movement of objects such as particles, vehicles, or humans and can be visualized as line paths . For instance, Hlawatsch et al. [9] present pathlines of simulated unsteady flow as small glyphs embedded in the simulation domain.

## 2.4 Relational Data

Finally, graph and hierarchies are often used to represent relationships between objects, for instance, trajectories abstracted to movement between regions or correlations between variables. Simple relational data of limited size can also be encoded in word-sized graphics as node-link diagrams . An alternative representation similar to a table is adjacency matrix , which encodes relationships as colored cells connecting the nodes listed in the rows and columns of the matrix.






## 3 APPLICATION EXAMPLE

To highlight the applications of afore-mentioned word-sized visualizations, we present the example of analyzing and visualizing eye tracking data. Eye tracking data includes the measurements of gaze

Table 2: Word-sized eye movement visualizations grouping users based on their search strategy to complete a task.

Visualization Type	Group A	Group B	Group C
Scan path			
Transition arcs			
Transition matrix			
AOI timeline			
Attention map			

points and eye movements patterns. It finds applications in various fields such as marketing, human-computer interaction, neuroscience, product design, and visualization research. More information about the usage and applications of eye tracking in data visualization can be found in the work of Kurzhals et al. [10]. The main reason to choose eye tracking data as an application example lies in the fact that it has temporal, spatial, and relational components and can cover many word-sized visualizations presented in Table 1. The following discussion is based on previous work [2]. This example shows how word-sized graphics can be used to present complex data embedded in text and tables in a realistic setting. Despite the specialization on eye tracking, many of the visualizations are generic and can be reused for other applications showing similar data, for instance, trajectories of particles or temporal events in processes.

In these eye tracking visualizations, a *scan path*  (*trajectory*) represents the eye movement path on a stimulus (the image or object viewed) with colored edges (blue to purple) encoding time. Transitions from one *Area of Interest* (AOI) to another, which semantically mark regions on the stimulus, form relational data and are depicted by *transition arcs*  (*node-link*) or a *transition matrix*  (*adjacency matrix*). The frequency of transitions in both of these visualizations is encoded in darkness of edges and matrix cells respectively. An *AOI timeline*  (*timeline comparison*) displays the temporal order in which different AOIs have been viewed, with the width of each box representing the duration of viewing. An *attention map*  (*heatmap*) visualizes the aggregated fixations and encodes duration of each fixation in the darkness of the grid cells.

To demonstrate what findings can be shown with these visualizations, we analyze the data of 20 users who participated in a controlled experiment [12], with visualizations available online.<sup>2</sup> The task was to find a public transport connection from an origin to a destination on a metro map, in the presented examples from Paris. The intermediate AOIs that the user might traverse to find the path are marked with colors (*origin* ■, *destination* ■, and others).











User 20 was the quickest  whereas User 16 was the slowest  to complete the task. User 17  and User 28  are the only ones who looked into the far-left end of the map. Empty lines in the transition matrices show that nine out of twenty users did not look at light green AOI (e.g., , , which implies that this AOI was not considered relevant for the task. User 36  forms an exception by not starting at the origin and User 4  by focusing the longest at the destination AOI. It is easy to see the users who immediately found a direct connection  and those who did not .



Table 2 shows three different user groups that are identified based on their strategy to complete the task along with various word-sized visualizations. Users in *Group A* quickly completed the task and did not explore all the possible routes to the destination (indicated by only few arcs in the *scan paths* and *transition arcs*). In contrast, the users in *Group C* verified their solution by exploring different options in detail (indicated by *AOI timelines*). *Group B* forms an exception by visiting those AOI regions that are not on the direct




way from origin to destination (indicated by *attention maps* and *scan paths*).


## 4 DESIGN CRITERIA

As demonstrated, word-sized graphics provide a versatile way to integrate data into text and tables. However, they also come along with some challenges and limitations. In contrast to large-sized visualizations, word-sized graphics are too small to carry axes, labels, or legends. Considering some criteria and guidelines may help design effective visualizations, we next discuss design aspects based on findings from the literature and our own previous experience working with word-sized graphics.



**Placement:** In this static document, we place the word-sized graphics in line with the text, but they can be also integrated between the lines of the text. While a study [7] has not yet provided conclusive results which placement should be favored, we decided for the *in-line* placement because it is more space efficient.

**Aspect ratio:** Since the height of a word-sized graphic is fixed, changing its size implies adapting its width, and hence, its aspect ratio. Like the term *word-sized* already indicates, such graphics are usually much wider than height. This unusual aspect ratio sometimes limits their applicability, especially for spatial data (e.g., a map) where a certain aspect ratio is given and should not be changed. For line and bar charts, the wide aspect ratio is not as restricting. However, Cleveland [4] demonstrates that a poorly chosen aspect ratio can lead to wrong perceptions by the readers. To avoid this, he proposes to compute the optimal aspect ratio so that the average orientation of a line segment in the diagram equals 45 degrees (*banking to 45 degree*:  → .

**Bounding box:** Tufte [13] recommends to not use any frame around the word-sized graphics because it might clutter the display and diminish the data content of the graphics. We agree that this effect can happen, especially when using a strong border line. However, we add thin border lines because the absence of grid lines, axis labels, and axis data ranges in a word-sized graphics sometimes makes them hard to interpret. Bounding boxes mark the exact extent of the graphics, which can be a crucial information, for instance, when providing reference values in a line chart  or when whitespace has a meaning like in a spatial diagram . For consistency reasons, we use the frame for all graphics. An alternative solution is to use a light background shade to mark the extent of the graphics .

**Labeling and legends:** While labels and legends cannot be integrated into a word-sized visualization due to scaling, they can often be woven easily into the surrounding text or neighboring table cells. For instance, colors can help identify distinct categories and a diagram  might represent data *before* ■ and *after* ■ an event.

**Color coding:** Like demonstrated in some of the above examples, also in word-sized graphics, quantities or categories can be encoded in color. Since it is perceptually more challenging to discern colors when the fill area is small, we recommend to use larger color or brightness contrasts than one would for regular-sized diagrams.

**Visual comparison:** Options for visual comparison are small multiples (juxtaposing several visualizations), superposition (overlapping information), and explicit encoding of difference. In our experience, juxtaposition works well with word-sized graphics; Table 2 provides an example of visual comparison based on juxtaposed word-sized graphics. Superimposition and explicit encoding are harder to implement because several layers or additional difference information usually increases visual clutter in the already visually dense graphics, but it works to some extent (e.g., , .

**Interactive documents:** When using word-sized graphics in an interactive document (e.g., in a Web page), additional information made available on demand (e.g., an enlarged diagram on click) may

<sup>2</sup>[http://etsparklines.fbeck.com/main\\_study.html](http://etsparklines.fbeck.com/main_study.html)

significantly improve the readability and usefulness of the graphics. For instance, Goffin et al. [8] describe interactive transitions from *document-centric* to *visualization-centric* views. Further, text and graphic can be better integrated if interactions illustrate the data connecting text and graphic (*vis-text interaction*) [3, 11].

## 5 WORD-SIZED GRAPHICS IN PRACTICE

With the increased popularity of word-sized graphics, more and more tools are facilitating their easy creation and embedding. However, the support is yet limited to simple line and bar plots in most cases.

For static documents, *Microsoft Excel* and *Google Sheets* allow the transformation of data into word-sized line and bar charts. The users can easily customize the visual appearance of created graphics and may add axis or borders. Similarly, *LaTeX* has packages such as *sparkline*, *spark*, *sparktex* for creating and embedding word-sized graphics in text and tables. These packages use simple commands for defining word-sized line and bar charts. However, the production of word-sized graphics for comparatively complex data (as mentioned in Table 1: spatial and relational data) is not supported by these tools and packages; custom-built graphics are required, but can be derived from available large-scale implementations of such visualizations.

In dynamic or Web-based documents, it is natural to have interactive counterparts of the word-sized graphics described in Table 1. There are many open source libraries and plugins that facilitate the creation of interactive word-sized graphics with Web technologies. For instance, *jQuery Sparklines* supports the generation of a large variety of interactive word-sized graphics enriched with animations and tool-tips. In addition to simple line and bar plots, it allows the generation of box plots, pie charts, composite line plots, or stacked bar charts. Other notable libraries include *Sparklificator*, *Peity*, and *React Sparklines*. All of these libraries use a simple syntax and declarative way to define word-sized graphics. *Sparklificator* also provides versatile placement options for the graphics such as *top*, *right*, or *overlay* [7].

## 6 CONCLUSION

In this work, we described various possibilities for producing and embedding word-sized graphics to visually augment text and tables. This approach can save space in publications and also promises to decrease cognitive load of readers by reducing the split-attention effect. The application example demonstrates how the results of a user study can be presented with integrated visualizations. However, the need of large-scale graphics for complex visualizations cannot be overlooked in static documents, and often a mix of both, small- and large-scale graphics, works best. In dynamic and interactive documents, the word-sized graphics can act as links and take the reader to larger version of the graphics on demand. With this, we hope to inspire scientists and engineers to experiment with word-sized graphics for an improved communication of data.

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