Survey on Visualizing Dynamic, Weighted, and Directed Graphs in the Context of Data-Driven Journalism

Christina Niederer, Wolfgang Aigner, and Alexander Rind

St. Pölten University of Applied Sciences, Austria
Christina.Niederer@fhstp.ac.at
Wolfgang.Aigner@fhstp.ac.at
Alexander.Rind@fhstp.ac.at

Abstract. Data journalists have to deal with complex heterogeneous data sources such as dynamic, directed, and weighted graphs. But there is a lack of suitable visualization tools for this specific domain and data structure. The aim of this paper is to give an overview of existing publications and web projects in this area by classifying the works in a systematic characterization that adapts existing characterizations for a focus on Data-Driven Journalism (DDJ). The survey highlights a lack of work in visualizing dynamic, directed, and weighted graphs, albeit individual aspects of dynamic graphs are well explored in the graph visualization literature. The results of this survey show that Sankey diagrams and chord diagrams occur frequently in web projects. A further popular method is the animated node-link diagram. The representation of a flow (directed and weighted) is typically illustrated as lines giving the direction of the relationship and width of lines showing the weight.

Key words: dynamic graphs, data-driven journalism, network, graph visualization, quantitative flow

1 Introduction

Today we live in a world in which it is increasingly important to understand different complex phenomena to facilitate well-informed decisions. Traditionally, journalists play an important role in uncovering hidden patterns and relationships to inform or entertain readers. In addition, the amount of available data is growing and, thus, it becomes crucial for journalists to use data science in their investigative work. This trend led to the advent of *Data-Driven Journalism (DDJ)* [1]. The journalists' workflow now includes dealing with complex heterogeneous datasets. Such datasets comprise multiple variables of different data types that often stem from different sources and are sampled irregularly and independently from each other. Moreover, specialized data types need to be managed and analyzed. Often, the data structure of dynamic, weighted, and directed graphs appears such as the Austrian Media Transparency Database [2] showing the flow of money over time between governmental organizations and media companies. Because of the complex data structure and the lack of software tools especially for journalists, there is a need for analysis of existing work in dynamic, weighted, and directed graph visualization.

A *graph* can be defined as a set of objects, called *vertices* (nodes), and their relationships, called *edges* (links) [3]. In contrast to a *static* graph, a *dynamic* graph evolves over time. As von Landesberger et al. [4, p. 1721] emphasize "[t]ime-dependent changes may affect the attributes of nodes and edges, the graph structure or both". A *weighted graph* assigns a numeric attribute, called weight, to each edge. Graphs are often classified into undirected and directed [5]. In *directed graphs* the vertices of an edge are ordered. Many visualization techniques have been introduced in the field of dynamic graph visualization [4]. A number of surveys [4, 6, 7, 8] of visual techniques and also task taxonomies [9, 10, 11, 12, 13] exist in the literature. The focus of these papers lies on dynamic graphs and the categorization of visual approaches. The currently available literature lacks a survey that addresses the specific and complex data structure of dynamic, weighted, and directed graphs. The paper at hand aims to extend existing surveys by providing an overview of approaches for dynamic graphs visualizations showing quantitative flows (directed and weighted edges).

In Section 2 we discuss related work. In Section 3 we outline the systematic characterization of the dynamic, weighted, and directed graphs. Section 4 contains the description of the results, we reflect on the outcomes in Section 5, and Section 6 proposes directions for future work.

2 Related Work

Various surveys, state of the art reports, and design space papers exist to provide an overview of dynamic/temporal graph visualizations. Von Landesberger et al. [4] conducted an analysis of large graphs with the focus on the aspects of *visual representation, user interaction,* and *algorithmic analysis*. The graphs are classified according to whether they are static or dynamic (attribute change, structural change, or both) and by graph structure (tree, generic graphs, and compound graphs). In 2014 Beck et al. [6] surveyed the state of the art in dynamic graphs by classifying visualization techniques in a structured hierarchy of three layers: *animation, timeline* and *hybrid techniques*. In the same year (2014) Kerracher et al. [7] presented the work of mapping the design space of techniques for temporal graph visualization. They identified two dimensions according to which the existing visualization techniques can be classified: *graph structural encoding* and *temporal encoding*. Hadlak et al. [8] created a meta survey, which is built on existing graph visualization surveys and identifies the four common facets of *partitions, attributes, time,* and *space*.

All these state of the art reports and surveys aimed for a categorization and classification of visualization techniques in the field of dynamic graphs visualizations. To sum up, the characteristics of temporal and graph structure are considered in all papers. However, we could not identify overview literature that focuses on directed and weighted flows in dynamic graphs in particular.

Also various task taxonomies in the field of dynamic graph visualizations exist in the literature. The design space of visualization tasks by Schulz et al. [9] and the multi-level topology of abstract visualization tasks by Brehmer and Munzner [10] are general but can to some extent be applied for graph visualization. In the field of dynamic/temporal graph visualizations, the work of Lee et al. [11], Ahn et al. [12], and Kerracher et al. [13] provide more specific task taxonomies. Together, these papers provide important insight into the field of dynamic graph visualization and tasks the users perform.

The aim of this survey is to provide an update by adding more recent publications and web projects in the context of DDJ and techniques for directed and weighted graphs to the body of work presented in the existing surveys. The focus hereby lies on dynamic, weighted, and directed graphs.

3 Systematic Characterization

Our characterization of work on graph visualization consists of three groups of categories: general categories, categories relating to time (dynamic graphs), and categories relating to flows (directed and weighted edges).

General. A first categorization is done by the *application domain* (e.g., economy, science etc.) of the project or publication. Then, a categorization by *visualization technique* will give an overview of the most common representations for these graphs. In addition, we will look at the *arrangement* of nodes. For every project and publication, the status of conducting an evaluation is documented as the type of *evaluation* (qualitative, quantitative, no evaluation, or unknown).

Time. Our categories relating to time are based on existing taxonomies in the literature on dynamic graph visualization: Based on the data sources behind the visualizations we distinguish between works for either dynamic or static graphs [4]. For work supporting time, we adopt the categorization of graph structure and time component from Beck et al. [6] and categorize time interaction additionally. For *graph structure,* they distinguish between animation, timeline, and hybrid techniques on the first level of their characterization. Animation is a time-to-time mapping, this means that the different timestamps are illustrated as an animated representation. If the representation of the graph can be drawn onto a timeline in a time-to-space mapping the categorization of the visualization is a timeline. Using animation in combination with for example a static timeline Beck et al. speak about hybrid approaches [6]. Also the categorization for *time component* into either superimposed or juxtaposed are based on the survey of Beck et al. [6]. In addition, we analyze interaction techniques and interface elements used to navigate time in the category *time interaction.*

Flows. Likewise, we classify publications based on the underlying data sources showing the *characterization* of directed or undirected and weighted or unweighted graphs. We study whether direction and weights are shown on edges, nodes, or both. This survey also examines the representations of quantitative flows such as using colors or width of a line showing the direction or weight of the relationship.

Literature Search. To collect relevant publications for this report, we started to work through publications in the state of the art report by Beck et al. [6], von Landesberger et al. [4], Hadlak et al. [8]. In parallel, we used different search engines such as Google Scholar, IEEE Xplore, ACM digital library, Springer Link, and Google.

At first we defined keywords to use such as "dynamic graph visualization", "flow visualization", "weighted and directed graph", "multimodal graph visualization", and also different combinations of them. Also keywords in the area of data driven journalism "journalism" or "data driven journalism" are used. These keywords were also used to find online material and projects in this domain. The examples presented in this report are appropriate to the domain of data driven journalism with the focus on quantitative flow (directed, weighted graphs).

4 Results

Six web projects in the domains of education [14], politics [15, 16, 17], sport [18], and economy [19] were found, that show quantitative flows. 10 publications, which are relevant for this report in the domains of neuroscience [20, 21], science [22, 23, 24], ecosystem [25, 26], and social networks [27, 28] can be identified. Four of the found publications have their focus on the development of visualization techniques for no specific domain. The overview of all publications and web projects is shown in Table 1.

4.1 Visualization Techniques

Seven of the found works are classical node-link diagrams [17, 20, 21, 22, 23, 29, 30]. Besides that, hybrid representations that adapt and combine techniques are popular. For example, Google+Ripples combines node-link diagrams and treemaps [27]. Further, the node-ring representation merges node-link diagrams with the inspiration of concentric circles [31]. Etemad et al. [25] presented Eco-Spiro Vis, a visualization specifically designed for ecological networks. The representation uses the circular character of the chord diagram in combination with aspects of Spirographs to visualize directed, weighted graphs. Farragui et al. [32] introduced a visualization method for dynamic graphs inspired by the tree rings of a tree, showing the age of a tree and the amount of new growth of a tree in a year. Greilich et al. [24] published a visualization method for visualizing weighted, directed compound digraphs called TimeArcTree (Fig. 1). Based on node-link diagrams they aligned the nodes of a graph vertically for each timestamp. Two publications use a matrix-based approach for dynamic graphs. The matrix visualizations are integrated in a multiple view layout or are part of a study comparing two visualization techniques [20, 21]. Only one paper uses a

Table 1. Classification of recent publications and web projects.

	Application Domain	Visualization Techniques	Arrangement	Evaluation	Static & Dynamic	Time Component	Time Interaction	Graph Structure	Graph Characterization	Direction/ Weights on	Quantitative Flow
Woher die Daten stammen [17]	politics	node-link diagram	circular	unknown	static	–	–	–	directed	–	line
Soccer Transfer Window [18]	sport	chord diagram	circular	unknown	static	not mentioned	–	–	weighted + directed	edge	flashing balls + animation
Media Transparency Database [15]	politics	sankey diagram	–	unknown	static	–	–	–	weighted + directed	edge	width of lines
Parteispenden [16]	politics	sankey diagram	–	unknown	static	–	–	–	weighted + directed	edge	width of lines
International Trade Flow [19]	economy	chord diagram	circular	unknown	dynamic	superimposed	check box	animation	weighted	edge + node	width of lines
VisualCinnamon [14]	education	chord diagram	circular	unknown	dynamic	–	–	animation	weighted + directed	edge + node	width of lines
GraphDiaries [30]	–	node-link diagram	–	qualitative	dynamic	superimposed	thumbnails	animation	–	–	–
GraphAEL [23]	science	node-link diagram	vertical	no	dynamic	juxtaposed + superimposed	–	animation	weighted + directed	edge + node	color + size
Tree-ring Layouts [32]	ego networks	Tree-ring	circular	qualitative	dynamic	juxtaposed	–	animation	directed	–	–
TimeArcTree [24]	computer science	TimeArcTree	–	no	dynamic	juxtaposed	–	timeline	weighted + directed	edge	color
DiffAni [29]	–	node-link diagram	–	qualitative	dynamic	superimposed	selection	hybrid	–	–	–
Visual Adjacency List [33]	–	matrix-based	–	qualitative	dynamic	juxtaposed	–	timeline	weighted + directed	node	–
egoSlider [28]	ego networks	glyph-based	–	qualitative	dynamic	–	–	hybrid	undirected + weighted	edge	color, width of line
Weighted Graph Comparison [20]	neuroscience	node-link + matrix	–	qualitative	static	–	–	–	weighted	edge	color, type of line
Visualization of Energy System [26]	energy system	sankey diagram	map	qualitative	dynamic	superimposed	slider	animation	weighted	edge	width of lines
Google+Ripples [27]	social network	node-link + Treemap	–	no	dynamic	superimposed	slider	animation	directed	–	curved arrows
Node-Ring Visualization [31]	not mentioned	Node-Ring	rearrangeable	no	not mentioned	–	–	–	weighted + directed	edge + node	color, size
Maps of Random Walks [22]	science	node-link diagram	–	no	dynamic	not mentioned	–	–	weighted + directed	edge + node	width of line, color (edges) color, size (nodes)
Spirograph Inspired Visualization [25]	ecosystem	chord diagram + Spirograph	circular	no	static	–	–	–	weighted	edge + node	width of lines + new technique
Network Flow [21]	neuroscience	node-link & matrix	circular	qualitative	dynamic	superimposed	slider	animation	directed	–	invisible path + animation

The grey area at the top of the table denotes the found web projects.

matrix-based approach to visualize dynamic graphs in the form of a visual adjacency list [33]. Sankey diagrams [15, 16] and chord diagrams [14, 18, 19] showing quantitative flows occur particularly often in web projects (e.g., Fig. 2 and 3). Alemasoom et al. [26] used Sankey diagrams to generate visualization of flows and correlations in an energy system. EgoSlider by Wu et al. [28] uses a glyph-based diagram in combination with a multiple view layout, giving more insights into the data of ego networks.

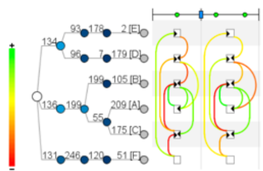

Fig. 1. TimeArcTree [24]

Fig. 2. Transfer Window [18]

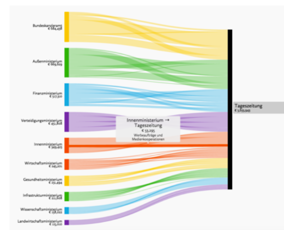

Fig. 3. Sankey diagram "Medientransparenz" [15]

4.2 Quantitative Flows

Quantitative flows are mainly depicted in the form of colors, width of lines, arrows, transparencies, animations, or flash metaphors as shown in Fig. 4. The most common representation of flows is the width of lines illustrating the weight of an edge, especially because this representation is used by visualization techniques such as Sankey diagrams and chord diagrams as well as node-link representations.

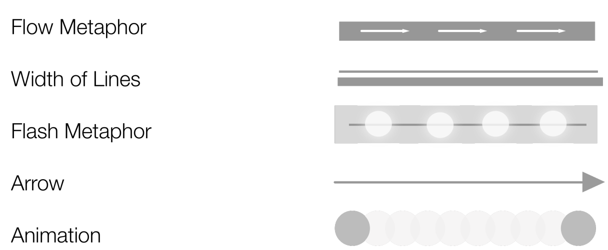

Fig. 4. Examples showing quantitative flows

4.3 Time

Two of the investigated publications use the timeline approach [24, 33] to show the time aspect. Also, two hybrid approaches can be found in the literature

[28, 29]. The most common visual representation are animations showing the changes over time [14, 19, 21, 26, 27, 30]. Erten et al. [23] and Farrugia et al. [32] use small multiples to visualize different timestamps and their changes in it. The visualization tools provide different interaction possibilities to navigate through time. The most common form are sliders [21, 26, 27]. GraphDiaries [30] integrated thumbnails giving an overview of the changes over time. Users are able to use check boxes to navigate through the visualization getting insight into changes over time [19]. To represent time, superimposition is most frequently used [19, 21, 23, 26, 27, 29, 30]. Moreover, a number of approaches use juxtaposition to give insight into the time changes [23, 24, 32, 33].

4.4 Evaluation

The most common evaluation methods are qualitative studies. Eight of 14 publications perform qualitative methods to evaluate their developed visualization technique. More than half of them do not integrate an evaluation in their research process. The evaluation status of web projects is not known.

5 Discussion

Only nine of 20 publications and web projects explored the possibilities to visualize weighted and directed graphs. The underlying data structure of three online projects are static, weighted, and directed graphs. Five scientific papers work on the problem of visualizing this special data type of dynamic, directed, and weighted graphs. Most of these developed tools use combinations of existing techniques based on node-link diagrams. Von Landesberger et al. [4] define the main challenge in using node-link representations to produce a readable layout. This includes no overlapping of nodes and less edge crossings as well as homogeneous edge lengths. It also seems to become important to find visualization methods addressing this problem and find possibilities to represent dynamic, directed and weighted graph data. The analyzed projects and publications are implemented in various domains like science, politics, social networks, sports, education, and neuroscience. Tools or visualization techniques for the domain or the special use case of DDJ are not explored in the literature. An interesting finding is that five of six online visualizations are based on Sankey [15, 16] or chord diagrams [14, 18, 19]. Only one uses a node-link diagram [17]. Often the weight of edges is shown as line width and represented together with direction by animation, which should give a visual metaphor for flow. Moreover, it became apparent that a circular arrangement of network nodes is quite common and has been found seven times. The results also show that the most common possibility for showing changes over time are animations, small multiples, and juxtaposed alignments. The interface elements to navigate over time are often sliders or checkboxes. More than half of the publications do not perform evaluations, the rest qualitative studies.

6 Conclusion & Future Work

This survey presents an overview of research literature in the area of visualization of dynamic, weighted, and directed graphs in the domain of DDJ. We updated the existing literature of dynamic graph visualization with recent publications and web projects. In addition, we focused on weighted and directed graphs due to their relevance for DDJ. The found publications are investigated along a consistent characterization that is derived from existing overview literature.

Further research should be undertaken to investigate the suitable representation of weighted and directed graphs changing over time. Alemasoom et al. [26], Chaoyu et al. [21] and Alper et al. [20] integrate existing visualization techniques as node-link or matrices in their tools. Other publications tried to combine different aspects of visualization techniques such as node-link based approaches [31] and chord diagram with Spirograph aspects [25]. For investigative exploration of graphs, new interaction possibilities for graphs should be developed. Other interaction techniques beside sliders and checkboxes are possible for interaction along the time aspect. Further interaction support for the flow aspect of graphs is needed.

Even though they were out of the scope of this survey, *multimodal graphs* are another aspect of graphs to be considered in DDJ. A multimodal graph can have different types of vertices [34] such as government organizations and media companies in the Austrian Media Transparency Database [2].

Large and complex heterogeneous datasets are the basis for most of the visualizations. The web projects often concentrate on a specific aspect, trying to communicate a certain message to the end user. The range of suitable visualization techniques is wide. So the investigation of those visualization methods to other domains and use cases could be part of further research.

The work of data journalists, which is related to the problem of working with complex data structure of dynamic, weighted and directed graphs, is not explored in depth. Most of the web projects address the end user, the consumer of online newspapers.

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