Adaptive Semantic Visualization for Bibliographic Entries

Kawa Nazemi, Reimond Retz,
Jürgen Bernard, Jörn Kohlhammer, and Dieter Fellner

Fraunhofer Insititute for Computer Graphics Research (IGD),
Fraunhoferstr. 5, 64283 Darmstadt, Germany
{kawa.nazemi,reimond.retz,juergen.bernard,
joern.kohlhammer,dieter.fellner}@igd.fraunhofer.de

Abstract. Adaptive visualizations aim to reduce the complexity of visual representations and convey information using interactive visualizations. Although the research on adaptive visualizations grew in the last years, the existing approaches do not make use of the variety of adaptable visual variables. Further the existing approaches often premises experts, who has to model the initial visualization design. In addition, current approaches either incorporate user behavior or data types. A combination of both is not proposed to our knowledge. This paper introduces the instantiation of our previously proposed model that combines both: involving different influencing factors for and adapting various levels of visual peculiarities, on visual layout and visual presentation in a multiple visualization environment. Based on data type and users' behavior, our system adapts a set of applicable visualization types. Moreover, retinal variables of each visualization type are adapted to meet individual or canonic requirements on both, data types and users' behavior. Our system does not require an initial expert modeling.

1 Introduction

Recent research in adaptive visualizations showed significant advances in human information processing ([1], [2], [3], [4]). The adaptation techniques were in particular adopted to search and exploration tasks ([2], [1]). The evaluation results of the implemented adaptive visualizations were promising, whereas the applied methods varied enormously ([2], [3], [4]). Today's systems apply visual adaptation either on data to provide a better suited visualization type ([5], [6] or to recommend data for users based on "points-of-interest" [2]. Further some systems investigate the interaction as baseline, whereas experts model the best suited visualization for the various tasks [7]. After a review on related work and to our knowledge, none of today's systems incorporates both: adaptive visualization based on (1) data and on (2) users within the analysis process without using the expert knowledge for visualization design. Thus interactive visualizations provide a problem-solving process for various tasks, e.g. searching, locating, analyzing or exploring ([8], [9], [10]), we propose that it is more valuable to provide an adaptation on different levels of visual variables considering the human

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vision perception ([11], [12], [13], [14]). An analytical task involves a more goal-directed and serial processing of vision perception [11], needs other variables to be adapted than "locating" a search result, which can be performed by providing a parallel perceived visual variable, e.g. a simple distinguishable color of one entity highlighting the from its distractors [15]. However, the combination of adapting both, type and retinal variable is not applied in today's visualization systems. Further the adaptation approaches, which involve multiple visualizations to comprehend the perspective on data, are rare. The involvement of users in the adaptation process is often performed only on individual level with limitation of experts, who has to create an initial user model. An overall improvement of the adaptation behavior, e.g. by implementing a canonical user model instead of using initial expert knowledge, is not considered in the existing approaches. Rather the individual user preferences are investigated without improving the general adaptation procedure. In this paper we introduce a novel adaptive visualization system based on our previously proposed model ([13], [14]). Our visual adaptive system focuses on a suggestion and automatic adaptation of both: best suited visualization types (Layout) and their visual representation (Presentation) ([13], [14]). Additionally, the user behavior is investigated in a "canonical user model" for providing a "learning" adaptive approach that considers the most common user beside only focusing the individual user behavior. We demonstrate our adaptive visualization system on real-world BibTeX entries of the Eurographics Association (EG) Digital Library. The application example is geared towards the field of Digital Libraries.

2 Related Work

2.1 Adaptive Visualizations

The term *adaptive visualization* is used for different levels of adapting the visual representation, filtering and recommending data to be visualized. Golemati et al. [16] introduced a context-based adaptive visualization that concerns user profiles, system configuration and the document collection (data set) to provide an adequate visualization. They state that the choice of 'one' adequate visualization from a pool of visualizations leads to a better performance. The adaptation of the visualization is based on the "context" which has to be generated manually. The rules for user classifications needs experts, who have to classify this aspect manually too [16]. An implicit interaction analysis is not performed; further the use of different visual variables is not investigated. A similar approach is proposed by Gotz et al. with the HARVEST tool [7]. HARVEST makes use of three main components: a reusable set of visualization widgets, a context-driven visualization recommendation and semantic-based approach for modeling user's analytical process. The result of the modeling component is used by the integrated visualization recommendation to choose one visualization for the analytical task and is limited to just one visualization. A further and essential limitation is the need of experts who have to define an initial design for the interaction patterns and the resulting visualization recommendation. [7] With the *APT tool* [5] and the consecutive *Show Me* system [6], Mackinlay et al. differ from the previously described works in a metaphor of small multiple displays and an enhanced aspect of user experience in visual analytics. Although they propose an adaptive visual system, the used algebra is defined for data to provide a better mapping of data-tables to visual representations. Another approach for data-adaptive visual presentation is HiMap [17]. The system reduces the graph-layout complexity (visual density) by implementing an adaptive data-loading algorithm. Similarly, da Silva et al. investigated the reduction of complexity by adapting the data [18]. They introduced a formal model for computing the degree-of-interest based on the main concept of an ontological data structure. These approaches are limited to adapting the visual representation based on the underlying data; the user is not investigated as influencing factor for the adaptation.

The adaptation of a spatial visual presentation layer based on user preferences is proposed in the *Adaptive VIBE* system by Ahn and Brusilovsky ([1], [2]). However, their approach does not provide adaptive capabilities for various data types and is limited to one visualization type and a point-of-interest provided by the user manually. [1] The introduced examples demonstrate the upcoming popularity of adaptive visualization concepts. However, the majority of the systems use either one influence factor or adapt to one visualization or visual presentation, but the main limitation is further the involvement of either experts to model an initial visualization design or the active involvement of users' that may be obtrusive for their work. An automated visualization adaptation by adapting the different levels of visual representations (Data, Layout, Presentation) ([13], [14]) is not being proposed, further the advantages of reducing the complexity by combining visualizations, adapting their presentations and make use of data types and user behavior has not been thoroughly investigated so far.

2.2 Visualizations for Digital Libraries

The visualization of bibliographic entries is a broad area with many efficient and useful techniques, especially in the field of Digital Libraries. The BiblioVis system by Shen et al. [19], the Citation Map of *Web of Knowledge* [20] and a methodology based on *Power Graphs* [21] may serve as examples. Similar to our work, multiple-linked views and a variety of graph-based visualizations were applied to provide additional value of bibliographic entries to the user. However, adaptive visualization concepts are not provided in that context. Chou and Yang presented the PaperVis system [22]. They combined a modified version of Radial Space Filling and Bullseye View to arrange papers as a node-link graph. It further provided a semantically meaningful hierarchy for facilitating literature exploration [22]. Bergström and Atkinson [23] presented PaperCube, a web-based approach for visualizing the metadata of a CiteSeer version. Similar to our approach, the authors integrated different visualization types for exploring the metadata and the correlations within the data-set in a web-based environment. Furthermore, PaperCube enables the choice between *article* and *author* and provides various features for gathering detailed information. In contrary to our approach, their user interface neither provides multiple-linked views, nor implements any adaptive behavior. [23] To provide a better access to digital libraries and find relevant information, adaptive visualization are required.

3 Approach

This chapter introduces the key technologies used for the proposed system. The main contribution of our application is to instantiate the visual adaptation model proposed in [13] and revised in [14] by combining several concepts and technologies. To face the proposed model various influencing factors, e.g. data and user are investigated to meet the adaptation of the visual representation on proposed levels of granularity. We chose the domain of digital libraries as an application example for the instantiation. We first give a brief introduction to the data integration and interpretation step of the system based on the chosen application example. Subsequently, we report on data-specific and user-dependent implications that influence the adaptive behavior of the visualization. Furthermore, we detail in how the adaptive capability of the system affects the automatic choice of visualization types (Layout) and visual variables (Presentation).

3.1 Data Processing and Light-Weight Semantics

The presented approach is capable for a variety of common data types. In the following, we describe the process of data integration and processing by means of the chosen application example on digital libraries. Our web-based visualization uses an API from the Eurographics Association (EG) for accessing the EG-BibTeX entries. We use simple HTTP-request to search in the EG-Library for results in *title*, *keywords* and *authors*. The result of the query is plain-text with BibTeX entry-results. We apply processing routines to improve the data quality. For a uniformed letter-comparison, a rule-based routine is applied that transforms all characters into the standard Latin character-set. Since a query on the EG database is applied on the three categories *title*, *keywords* and *authors*, the result may contain duplicates. We remove these redundant result entries by a duplicate detection routine. In a preliminary test case, we identified the need to disambiguate the author's names. To overcome this problem, we apply a rule-based algorithm that compares the last name, the first name, the first character of the first name, the coauthors and the ACM CSS. Figure 1 illustrates the system's disambiguation of the name 'Fellner' in the EG-Library. As a next step, we create a semantic schema based on the respective BibTeX metadata classes relation extraction. For example, we formalize paper authors as 'co-authors of' each other provide the relation 'written by' to papers and their corresponding authors and assign the relation 'author of', in return. This simple but efficient schema subsequently enables the adjustment of visualizations between different metadata attributes. The obtained network of metadata attribute relations is presented by graph-based visualization types. The ACM CSS data enables the creation of a lightweight hierarchy of publications. This additional information, encoded as a hierarchical data structure, is visually presented in the system with hierarchical aggregation metaphors. Since the data processing is executed in real-time, additional persistence layers are not necessary. Rather, the system is capable of immediate changes in the EG-library.

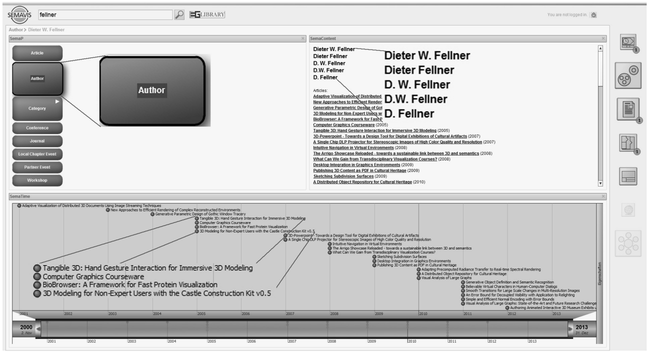

Fig. 1. Illustration of the search result for the term "fellner" in a multiple-visualization cockpit generated automatically the with adaptation techniques

3.2 Adaptation of Visualizations

Our application integrates a set of seven visualization-algorithms that are responsible for the placement and arrangement of the objects on the screen. We separate the visual presentation and spatial arrangement (Layout) of the objects, based on the research outcomes of vision perception ([12], [11]), to provide a more efficient adaptability. The visualization-algorithms can be combined in a visualization cockpit with an enhanced brushing and linking metaphor [24]. We further enhance this approach by automating the selection of appropriate visualization-algorithms based on the search result. Therefore each visualization-algorithm is annotated with its visualizing capabilities. Graph-based algorithms visualize the relationships between different and within categories (authors, articles, conferences etc.) (see Figure 2 right visualization), a time-based visualization illustrates the temporal spread of the results (see Figure 2 bottom), a Treemap-similar visualization [25] provides the ability to browse within the categories (see Figure 2 left) and lists with textual information provide the content of the found results (see Figure 1 right visualization).

The capability of each visualization algorithm is one indicator to recommend and automate the selection of the most appropriate visualization algorithm. Another indicator is the users' interaction with visualizations. We enable the users to place visualizations into the user interface or to remove them and enhanced the interaction analysis and prediction algorithm proposed in [26] to investigate the users' choice of combined visualizations. The user interactions on visualizations placed on the screen and the choice of alternative visualizations or their movement from the screen are used to derive a canonic user model. [27] Our canonic user model, models the behavior of all users by analyzing the interactions with

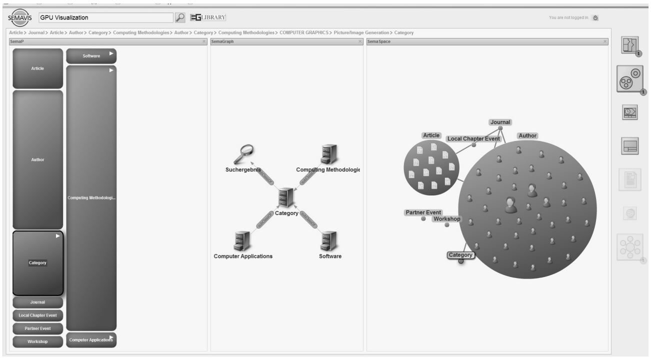

Fig. 2. Illustration of the search result of the term "GPU visualization" in a multiple-visualization cockpit generated automatically the with adaptation techniques

system based on the KO*/19 algorithm [26]. Therefore users' interactions are transformed in a numerical, internal representation and the Steady State Vector is determined as a relative measurement for the occurrence of interactions. [26] The model involves the interaction quantity with each data element, visualization element and the choice of visualizations to enable a learning system that considers the behavior of the majority of users. Further it provides general usage information of the visualizations to enable the recommendation and automatic selection of visualization-algorithms. The canonic user model does not require personal information about the user because the model itself provides a general data-dependent "initialization". To overcome an over-generalization of visualization choice, the canonic user model is counterbalanced with an additional user grouping, based on individual interactivity preferences and behavior. Thus, the system provides the capability to respond to individual users. For this, we implemented an algorithm that computes the deviation of the user interaction behavior. Therefore the user-interaction behavior of the current user is compared with the canonic user model with respect to the number of users. This enables to estimate, if the same or a similar user is interacting with the system and can be enhanced to group the users with diverting intentions. The approach provides two different modi for user-oriented adaptation. First the canonic-user model that investigates the behavior of all users and second an individualized user model. The individual user model is an instantiation of the canonic user model with certain preferences and interaction history of a certain user. If a user is interested in getting behavior-based visual adaptation, he is able to log-in as individual user. The default user model in our approach is the canonical user model. It is activated, if an individual user is not logged-in. The automatic selection and recommendation of the visualization-algorithms is one adaptation characteristic of our application. In addition the visualization layout is decoupled from the visual representation ([13], [14]). We define *visual presentation* as the sum of those visual or retinal variables, which can be perceived by human in parallel [15], e.g. color, shape, texture, size etc. of edges, nodes, objects etc.

([13], [14]). Our approach uses the visual presentation for quantitative information of the underlying results or for specific user preferences on content. The number of results is used as an indicator for adapting the visual presentation. For example, the system highlights the authors with the most publications. If the individual user model is activated by the user, the visual presentation can be used for recommending content. Therefore, the history of her interactions is considered with a subsumption of the hierarchy of the schema she interacted with. For example if the user is more interested in user interfaces and visualizations (based on his previous interactions) and searches for the author *fellner*, our application presents the 'categories-of-interest' visually highlighted (see Figure 3 top illustration). In contrary the canonical user model applies the number of results as indicator for the visual variables (see Figure 3 bottom illustration). Visualizations that are not applicable for currently analyzed data types are temporarily excluded from the set of user-selectable visualization types. If the data type changes within the exploration work flow, the system automatically adapts the set of provided visualization types. For example, the user may request all publications of a specific author on demand. In this case the system automatically adapts the visualization for the specific results during the interaction with a visualization transformation. Changes in provided visualizations are performed as unobtrusively as possible in order to not confuse the user. This is achieved by automatically suggesting the most similar visualization type (e.g. aim to apply a graph-based visualization when replacing another graph-based visualization). Although the transformation phases between two visualizations have not been considered as irritating by the test users in the development phase, we aim to conduct a formal evaluation as future work to measure the obtrusiveness of a change while a user interacts with the system.

With the described approach we introduced a way how visualization can be adapted to various influencing factors, e.g. data and users. An initial design for the visual adaptation is not required anymore, thus the canonical user model provides a self-learning approach and improves the visualizations with each user. Further the adaptation output was enhanced by separating the visual variables into Layout and Presentation. [14] This enables a fine-granular adaptation of visualizations.

4 Application Scenario

In the previous section, an abstract overview of the application was presented, comprising the real-time access to a web API, a system design combining multiple types of adaptive visualizations and a user-centered recommendation system for various visualization types. We now demonstrate the applicability of the system and the system behavior. The starting point of the application is a blank user interface with a search field at the upper left, a log-in button at the upper right and icons for visualization recommendation at the right (Figure 3 right vertical bar). A search space definition (like the authors category) is not needed, thus the system recognizes automatically the search space. In Figure 4, the user started

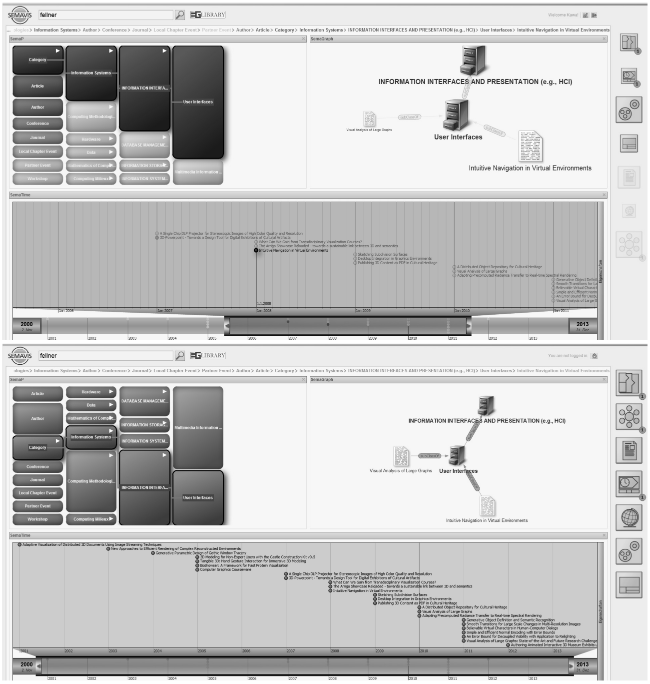

Fig. 3. Presentation Adaptation: the first visualization (top) illustrates the visual adaptation based on the behavior of an individual user, recommending relevant content; the second visualization (bottom) uses the canonic user model and adapts the visual presentation on the quantity of results.

the search with the textual query for ‘GPU visualization’. Here, the adaptive application provides two visualizations and highlights the category *article*, thus the majority of the results was found in articles. In the first very simple view he recognizes that there are a couple of articles found, the articles have relations to workshops, journals, etc. and there are more entities found in authors (as authors of the articles) than articles. If the user clicks on a category, a third visualization is added by the system to provide the navigation through the categories and the related articles. She is now able to put new visualization into the user interface, e.g. for investigating the temporal spread of the articles over time or to navigate through the results and explore the results. Figure 2 illustrates this case combined with a click on authors. The authors are represented by icons with different sizes, indicating the amount of articles related to the search. The user is now able to explore the results with the given visualization or put new visualizations into the user interface. Visualizations that are not able to illustrate the current set of chosen data are blocked and cannot be chosen. While navigating through the visualizations it may occur that new visual representations appear or the visual representation changes, e.g. by clicking on article, textual information appears on the screen. If the user searches for the term ‘fellner’, he gets another view on

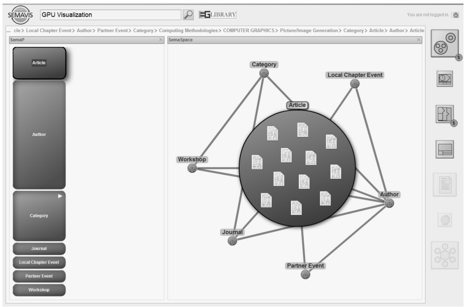

Fig. 4. Visualization of the results on the search "GPU visualization"

the same BibTeX data (Figure 1): First, the Treemap-similar visualization highlights the category 'author' and provides an overview navigation on the results, second a textual representation of the various (disambiguated) writings of the author's name, the related articles and coauthors and a temporal view on his publications. If an author cannot be disambiguated, an additional visualization provides the possibility to refine the search results.

5 Preliminary User Study

We conducted a preliminary user study to evaluate the canonic user model and the adaptive behavior on the presentation level. A between-subjects-design was chosen involving 14 participants (71.43% female, average age 24.5 years). The participants were randomly distributed over two experimental conditions. A Linked-Open Data web source was chosen. The applied adaptive concept was based on the canonic user model and adapted the size, color and order of the entities. Both of the groups of participants were requested to solve identical search tasks. The independent variable of the study setup was the visual adaption capability. One of the two groups was tested with adaptive visual presentation while the other group ran the tasks without visual adaptation. As our hypothesis we expected that the users of visualizations with visual adaptation are performing more tasks in the same time. The goal of the study was to determine whether the visual adaptation of the presentation leads to a better performance with respect to search tasks and higher user acceptance of the visualizations. In order to measure the performance during the tasks the participants behavior was logged (task-completion-time, derivation from optimal path etc.). For measuring the acceptance, the INTUI questionnaire [28] was used, which measures the intuitiveness of applications. In particular, the questionnaire items for measuring the *Magical Experience* and Gut Feeling were important, thus these correspond to positive emotions. [29] A between-subjects multivariate analysis of variance was performed on six dependent variables: the number of correctly answered questions and the five sub-scales of the INTUI questionnaire. Also kolmogorov-smirnov tests (KS-tests) were performed to ensure normality with an inference statistical procedure. The effects of the condition are shown in Figure 5.

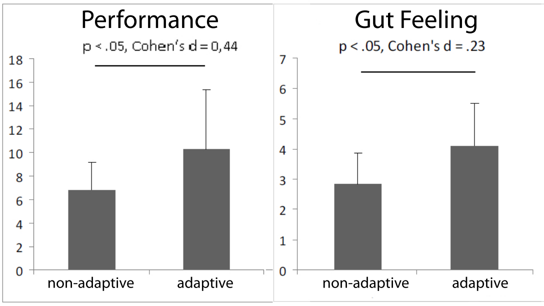

Fig. 5. Evaluation results on performance and *Gut Feeling*

Our hypothesis was confirmed by the data. The participants using the adaptive variant were able to answer more questions correctly than the participants using the visualization without adaptive behavior, F = -4.86, p = .0385. This result was expected, hence a one-sided test for significance was performed. Also participants in the condition adaptive visualization scored significantly higher on *Gut Feeling* (F = 1.29, p = 0.365), as expected, they perceived their actions more guided by gut feeling. The variables *Magical Experience, Verbalizability and Effortlessness* showed no significant differences between the conditions.

6 Conclusion

This paper introduced the instantiation of an adaptive reference model ([13], [14]) as an adaptive visualization application for bibliographic entries in digital libraries. We used a couple of existing visualization techniques, adaptation and user interaction algorithms and a technique of generating light-weight semantics to provide a novel approach for visual adaptation. The main contribution was the separation of the visual layer into layout and presentation for a fine-granular adaptation of visualizations. The integration of user models on individual and canonic level in combination with the data-attributes provided a user- and data adaptive behavior without the need of an expert to design the visual layer. The approach was exemplary adopted to bibliographic entries in a digital library. We proposed that the combination of adaptive visualizations with the generation of light-weight semantics can support users in their search and exploration tasks and improve the user experience. Even though our evaluation was preliminary, the case study led to very promising results.

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technology, developed by the Fraunhofer IGD (`http://www.semavis.net`). SemaVis provides a comprehensive and modular approach for visualizing heterogeneous data for various users.

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