A Context-Based Adaptive Visualization Environment

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Abstract

Digital libraries and historical archives are increasingly employing visualization systems to facilitate the information retrieval and knowledge extraction tasks of their users. Typically, each organization employs a single visualization system, which may not suit best the needs of certain user groups, specific tasks, or properties of document collections to be visualized. In this paper we present a context-based adaptive visualization environment, which embeds a set of visualization methods into a visualization library, from which the most appropriate one is selected for presenting information to the user. Methods are selected by examining parameters related to the user profile, system configuration and the set of data to be visualized, and employing a set of rules to assess the suitability of each method. The presented environment additionally monitors user behavior and preferences to adapt the visualization method selection criteria.

1. Introduction

Information technology continues to generate increasing amounts of data, and visualization systems (VSs) have emerged as a promising approach for assisting users in understanding, analyzing and managing these high data volumes [1] and providing information insight [2]. VSs have been extensively employed in various domains, e.g. scientific, statistical, stock-market trades, computer directories, or document collections [3].

Insofar, an extensive number of visualization methods have been proposed (e.g. [3], [4], [5], [6]), significantly varying in a number of aspects, including the target domain, the tasks supported and the type of data that are visualized. This suggests that a particular visualization method may be more effective when applied for executing specific tasks on data having specific properties, or, equivalently, that there is no single visualization method that can be considered to be "best" for all tasks and data sets. Furthermore, the efficiency of a visualization method may depend on factors pertaining to the available hardware (e.g. a method may yield optimal results if 3D displays or data gloves are available) and the profile of the current user (e.g. computer skills, knowledge of the data space structure, personal likings and aversions).

The present paper suggests a visualization environment, in which a set of visualization methods/tools are matched against the user, task, system and document contexts. This visualization environment is under development for the Historical Archive of the University of Athens, to assist researchers and other visitors in their information retrieval tasks.

2. Related work

In describing the role of user modeling in Visualization Supporting Systems, [7] mentions that the experience and capabilities of a user should cause the VS to change and adapt to him/her. To this end, a VS should (a) accommodate user models and (b) consult them when visualization methods and/or their operational parameters are selected

[8] suggests three kinds of user modeling: i) *the explicit modeling*, where the user model is directly extracted from the user through straightforward questions. It usually refers to initial information on a new user starting to interact with a VS. ii) *the implicit modeling*, information extracted from the user's interaction with the system (keys and functions used, choices etc) and iii) *special tasks to solve*, information extracted from the user after having him/her involved in solving special predefined tasks (i.e. implementing color deficiency tests, a system can distinguish the color recognition abilities of a user).

In [7], a user model has been suggested to constitute the basis for an adaptive VS. They designed computer tests and games to test user abilities such as color perception, color memory, color ranking, mental rotation and motor coordination.

[9] claims that successful visualization environments do not depend on a single powerful visualization, rather than on a whole set of visualizations, appropriate for various tasks and data types. In accordance to this it presents IVEE, a VS supporting multiple visualizations and dynamic queries. Although user input is restricted on his/her widget selections and the available visualization layouts conceal important document properties (hierarchical structure, hypertext structure etc.), IVEE provides a variety of visualizations and features to guide users in extracting information.

A number of 2D and 3D interface models have been implemented in the Periscope system [10] such as a holistic, an analytical, a hybrid as well as a specialized model to give the user the opportunity to select a specific presentation method to focus on certain properties of the results obtained. The user can assign search result attributes to visualization dimensions, and therefore, modify the method of visualization to highlight important features of the search result. Furthermore, comparisons between results from two or more different queries are allowed in a single 3D scene.

The work described below is based on the user modeling and system adaptive concepts. The proposed visualization environment combines existing visualization methods and user-context extraction procedures, resulting in a novel user-sensitive information space.

3. Context Modeling

3.1. User Context

Users who come to the Historical Archive to retrieve any piece of information vary in multiple ways. For example, they have different educational levels, ranging from users who only attended elementary or secondary school to users who possess degrees of expertise (MScs, PhDs) in various scientific subjects. They also have differences in their experience with using a computer, ranging from those who are beginners to the ones who are very experienced. But even those who are expert in using the computer, they have different ways in foraging the information they are interested in, and these differences depend on individual preferences and existing knowledge. Individual differences constitute a major factor that influences the user profile. Besides personal preferences and existing knowledge, cognitive abilities, specific aims and tasks to be solved, the gender, the age, the profession and the living environment of the user constitute the property of individuality, which defines a fundamental part of the user profile. Moreover, the steps a user performs while trying to reach the information needed, the -so called- history of the user, plays an important role in sketching out his/her profile and deciding which VS suits him/her best, so as to employ this system the next time s/he returns to search for information. Important properties related to the user profile are listed in table 1 (the list is not exhaustive). The list is based on [11] and has been adapted to fit the profile of the historical archive users.

Table 1. User context properties

Education	• Primary • Elementary • Higher
University relation/role /title	• Faculty members • Administrative personnel • Student • None of the above or no relation
Information Retrieval Knowledge	• Perfect • Medium • Novice
Aim	• Research • Publication • Personal Information
General	• Age • Gender • Profession
Abilities	• Visual memory • Arithmetic memory • Color recognition

3.2. System Context

In addition to the properties related to the profile/model of the user, the effectiveness of a visualization method may also depend on the available hardware and the peripheral devices attached to the computational system used for information foraging. Computational systems vary as well as users do; different input devices can be used, ranging from traditional mouse and keyboard to joystick and even 3D devices and sensors. The output devices also influence the decision about which visualization to use. Traditional 2D displays are not the only representation means available, as recently 3D displays and VR equipment are being used in more and more applications [12]. Processor capacity, memory size and any other computational equipment provide also important information on how to better exploit existing hardware in the service of the user's information retrieval needs.

Important properties related to the system context are listed in table 2 (the list is not exhaustive).

Table 2 System context properties

Input devices	• mouse • keyboard • joystick • Specialized input devices (3D mouse, glove, etc.)
Output devices	• 2D monitors • 3D monitors • Head mounted displays
Other hardware equipment	• Processor • Memory • Graphics

3.3. Document Collection Context

Finally, the characteristics of the data or document collection should be modeled. Every document collection has its particularities, which influence the effectiveness of a VS. The Historical Archive of the University of Athens contains documents issued since the foundation of the University up to quite recently, which are classified in categories. The number of documents contained, the categorization criteria, the existence of sub-categories and so forth, are important factors implying diversions in multiple document aspects (document creation time period, organizational division of origin, type of content -e.g. regulation, invitation, announcement etc).

The documents also vary in their format ranging from text documents (mainly), but also pictures, audio and video documents. Text documents in particular, need to be further distinguished into:

- Documents for which full text is available
- Documents which have been scanned into image format
- Documents not available in digital format.

In the context of the Athens University Historical Archive, the minutes from the various university meetings (senate, faculty, department, etc), are also considered as a special case, since firstly these are the set of text documents mostly requested by the archive users and secondly a minutes document usually contains a number of different subjects (management, academic, financial, etc), with each of these subjects probably requiring a different visualization method.

Document metadata (author, title, related keywords, document size and type) add an important component in the process of selecting the most appropriate VS.

Finally, the origin of the document collection should be considered: a *static collection* is the outcome of selecting one or more branches of a categorization scheme, typically in a drill-down browsing pattern, while a *dynamic collection* is formulated by evaluating a query against the full text or the metadata of the available documents. Static collections usually have a hierarchical structure which can be used as a visualization aid (through trees or other methods), whereas dynamic collections do not necessarily have such structures, the query terms however can be exploited in the resulting document set visualization.

Important properties related to the document collection context are listed in table 3 (the list is not exhaustive).

Table 3 Collection context properties

Categories of documents	• Criterion of categorization • Number of elements • Relation between categories
Text documents	• Full text • Image • Manuscript only • Meetings' minutes
Metadata	• Author • Title • Type • Department of issue • Keywords
Collection origin	• Static • Dynamic

4. Visualization methods and their selection

Having modeled the user, system and document collection properties for the visualization task at hand, the proposed system proceeds to select the most appropriate visualization method. This decision is taken by determining the visualization method properties needed to efficiently support the current task and, subsequently, matching the computed property list against the feature profile of each available visualization method. To this end, the visualization method properties should be formally modeled and an automatic set of rules for matching contexts (user, system and collection) to visualization method properties should be developed. The property model and the selection method are described in the following paragraphs.

4.1. Visualization Method Properties

In designing a VS, several issues are taken into account. The principle goal is to bridge the user with the information source, in the best way possible. Building such a bridge is not a simple task, as many parameters have to be taken into account. Typically, the design of a VS has a specific focus. Its designers use intelligent procedures in achieving that focus. In this way, every one of the systems has its own properties, which make it unique in improving a specific aspect of the information foraging.

For example, there are visualization methods which try to display full text documents in the most effective way, using thumbnails, highlights, document size and type cues, color codings, showing relations between terms, etc. Other methods, concentrate on improving focus + context techniques, in order to give the user alternative views to the document collection, using zoom in and out functionalities, graph rotation, hyperbolic spaces etc. A very common issue in large document collections which are structured in hierarchical way is how to visualize this hierarchy in an effective and easy to explore way. Important solutions to this issue have been proposed by introducing the third dimension in the visualization design, using tree-like layouts, real world metaphors, nested items, transparency/solidity functionalities etc. One of the main concerns, a Historical Archive has to deal with, is the managing of temporal information, i.e. information that vary with time. To facilitate the user in retrieving such information, visualization methods employ time axes in a variety of ways: bar charts, time lines, spirals etc. Another important concern in designing a visualization method is the representation of the relation between documents. This issue is effectively addressed using links between related documents, or clustering techniques, which bring together the related documents, color codings which reveal existing relations, etc. In a similar way it is addressed the problem of the representation of the relation between the query terms and the displayed results.

Finally, since a data collection is not restricted in text documents, many visualization methods focus on designing novel techniques to facilitate the user to retrieve and view picture, audio and/or video documents.

A list of basic features of VSs is depicted in table 4 (the list is not exhaustive). The first column lists the visualization method property, while within the second column the possible values for this property are presented. Each value is followed by an indicative list of visualization methods for which the specific property/value combination applies. Note that some visualization methods may support multiple values for a specific property (e.g. the PLAO visualization method [13] may operate both in 2 and 3 dimensions), in which case the method is repeated under all pertinent list elements. Note also that in some cases, either a feature is supported or not (e.g. color coding). In these cases, no value list is provided in the second column; a dash is used instead, followed by the list of methods supporting the feature. References are not provided in this table due to lack of space.

Table 4 – VS Properties and respective values

Number of dimensions	• 2 (PLAO, IVEE, …) • 2 ½ (Data Mountain, LookMark, …) • 3 (PLAO, IVEE, Perspective Tunnel, …)
Metaphor	• Landscape (Information City, Vineta, …) • Book and Library (WebBook, CAVE-ETD virtual library, …) • Perspective Planes and Panels (Data Mountain, Lookmark, …) • 3D Geometric Shapes (Information Pyramids, VizNet, …) • Trees and Graphs (Starwalker, Visible Threads, ….)
Interactive browsing supported for documents of type:	• Article (UVA, SPIRE, Doc Cube, …) • Publication (Bead, Vineta, Cat-A-Cone, UVA, …) • Hypertext (Data Mountain, LookMark, WebBook…) • Photograph/Video (Viz-Net, Dynamic Timelines, …)
Supports user-defined grouping for documents of type:	• Articles (-) • Books (WebBook, Web Forager, …) • Hypertext (WebBook, Web Forager, …) • Photographs/Video (-)
Color coding	• - (File System Navigator, Harmony Information Landscape, …)
Term frequency	• - (Tile bars, PRISE, Themescape, …)

4.2. Visualization Method Selection

The visualization method selection procedure matches properties from the user, system and collection contexts against the VS properties. To enable this matching, a rule database has been constructed, containing rules with the following format:

(context-property, vis-method-property, score)

where *context-property* is a property from the user, system or collection context, *vis-method-property* is a VS property and *score* is a numeric metric in the range [-10, 10] expressing how appropriate visualization methods having the specific *vis-method-property* are considered for contexts where the particular *context-property* holds. For example, the rule

(sysctx-display-3D, vismeth-noDimensions-3, 6)

declares that visualization methods employing three dimensions are considered quite appropriate for system contexts with 3D displays, while the rule

(colctx-origin-dynamic,
vismeth-itemgroup-hierarchical, -4)

expresses the belief that a visualization method, employing hierarchical item grouping, is inappropriate for collections that have been formulated by means of submitting queries. The rule database has been developed by interviewing users and VS experts, who were asked to match context properties against visualization method properties. The interview results along with published evaluation results of VSs (e.g. [14], [15], [16], [17]) were used as input for the population of the rule database.

When a collection needs to be visualized, the system firstly compiles the full set of context properties, which is denoted as CP. Subsequently, it traverses the list of available visualization methods, extracting for each method M the set of method properties P_M, which is used to compute a *total score* for method M. The total score is given by adding the score field *s* of all rules R = (cp, vp, s), for which cp $\in$ CP and vp $\in$ P_M. Finally, the visualization method with the highest total score is selected to perform the visualization. Effectively, this step examines whether the properties of the visualization method are considered appropriate for the current context parameters, as this is determined by the rule base. Note that under this scheme the absence of any rule correlating a context property *cp* with a visualization method property *vp* has the effect that property *vp* is considered "neutral" for contexts having the property *cp*, removing thus the need to insert rules of the form *(cp, vp, 0)* to explicitly state such property orthogonalities.

4.3. Adaptive features in method selection

The visualization method selection process described in section 4.2 does not take into account the *dynamic profile* of the user, as this is exhibited by the user's preferences and dislikes while working with the system. This dynamic portion of the user context is accommodated by complementing the rule list described in section 4.2 with a user-specific preferences database, which hosts information regarding:

- whether the user has considered a visualization method suitable/not suitable for a specific context.
- whether the user likes/dislikes a specific visualization method altogether.

This information is collected from the user, when the visualization task is completed (the respective window is closed) and when an alternate visualization method is requested. More specifically, the "close window" user interface widget unfolds a drop-down menu with the options "The visualization was satisfactory", "The visualization was not helpful for this data collection" and "The visualization was obscure/unusable", from which the user selects one. If the response to this drop-down is "The visualization was obscure/unusable", then the dynamic user profile is augmented with a record of the form

(dislike, viz-meth)

stating that the user has a negative stance against the specific visualization method in general. Note that this does not inhibit the use of the visualization method in a future case; such records are taken into account by the visualization method selection procedure to reduce the total score for the specific method (described below). The method however *could* be selected if it is found to score significantly higher than other methods a specific context. If the user selects one of the two first replies, then a record of the form

(eval, system-context, collection-context, viz-meth, score)

is added to the dynamic user profile, where *score* is "1" or "-1", depending on which response was selected. Note here that when the user chooses one of the first two replies, the visualization method is considered helpful/not helpful *for the current context*.

The rules within the dynamic user profile are taken into account for selecting the most suitable visualization method in system context SC and collection context CC according to the following scheme:

- if a (dislike, viz-meth) rule exists in the dynamic user profile, then the total score for the specific visualization method is decremented by 15.
- for the second form of rules, when the total score for a specific visualization method is computed, the system retrieves all the rules R_{dc} = (eval, sys-con, col-con, viz-meth, score) pertaining to this method. Subsequently, a *similarity metric* between (sys-con, col-con) and (SC, CC) is computed, to determine which of the rules is associated with a context best matching the current context. The value of the similarity metric falls in the range [-10, 10], where -10 is used for "totally different" contexts and 10 is used for "exactly matching" ones. The rule with the highest positive similarity metric is finally selected, the similarity metric is multiplied by the "score" field of the rule (1 or -1, depending on whether the visualization was considered helpful or not in the specific context) and the result is added to the total score for the visualization method under consideration. If no rule has a positive similarity metric, then the total score for the visualization method is not altered.

The rationale behind the computations performed using the second rule form is that if a visualization was found to be helpful/not helpful in some context, then it is "almost certain" this perception will hold for identical contexts; if, however, two contexts differ in a number of parameters, then the certainty level of this belief drops. This certainty level is reflected in the context similarity metric, while the multiplication by the "score" field simply renders the outcome positive for "helpful" visualizations and negative for "not helpful" ones.

Besides the "close window" widget, the user interface hosts the "Switch visualization" button, which provides the ability to visualize the same collection with an alternate method. A user may reach this decision because "An alternate view to the data is desired", "The visualization was not helpful for this data collection" and "The visualization was obscure/unusable", which are the same options listed when the "Switch visualization" button is clicked. In all cases, the dynamic user profile is updated in the same way that was described for the "close window" widget.

5. Conclusions and Future Work

In this paper we presented a context-based adaptive visualization environment to support information retrieval tasks in a Historical Archive. The proposed environment uses a visualization library, where pre-selected visualization methods have been registered, along with their properties. Visualization method properties are matched against the task context, which includes static and dynamic user profile, system configuration and information regarding the data collection, in order to select the most prominent visualization method for the task at hand. Matching is performed through a set of rules, accommodating both generic properties (e.g. number of dimensions in the visualization, color-coding) and method-specific properties (e.g. radial graph layout).

Insofar, the design of the system has been completed and a first prototype is being implemented. Besides the completion of the prototype, future work will focus on a thorough system evaluation, which will provide feedback both on the overall system effectiveness and for fine-tuning the rule database, and especially the "score" field. Monitoring specific user activities and behaviors (e.g. idle tile, use of "reset visualization" functions, erroneous activities etc) for enhancing the dynamic profile will also be considered.

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