Designing an intelligent human-computer interaction environment for information retrieval in the context of an Historical Archive

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Abstract This thesis focuses on the design of an intelligent human-computer interaction environment for information retrieval in the context of an Historical Archive. A user interaction environment is proposed, which hosts a set of different visualization methods. The proposed environment also incorporates a data base where the characteristics of the hosted visualization methods are recorded, and also user profiles –both their static and dynamic parts- are stored. These pieces of information are complemented with the characteristics of the data collection that will be visualized and subsequently the evaluation rules are employed, in order to determine which is the most suitable visualization methods for the situation at hand. Future work includes the incorporation of innovative visualization method, further elaboration on the cognitive effects of visualization methods, and mechanisms to dynamically update the rule base

1 Introduction

In the field of information visualization, new visualization systems appear quite frequently in order to improve information search and browse. These systems cover many aspects of information retrieval and knowledge extraction activities, provide different views of the data set and are equipped with many functionalities in order to be as useful as possible for their users. However, regardless of a thorough visualization design, the systems remain unable to satisfy any possible need and task: trying to solve a specific information retrieval task is not a uniform process. This is owing to the variety and disparity of factors that surround any specific task.

The most important of these factors is the user's individuality, which is the set of personal components which synthesize both the external and the internal identity of a specific user, and activate different behaviors when different tasks, or even the same task under different circumstances, is being elaborated on. Next, the users increasingly rely on electronic aids when they search for information (partly due to necessity, since the sheer volume of the information increases rapidly), and are continuously presenting new and complicated demands. Finally, each visualization system is typically designed taking into account the requirements of a specific task set and a selected user group, thus its features and modalities –however generic they may be- are significantly influenced by these aspects. Consequently, any individual visualization system is never enough for any possible need and task.

As a solution to this problem, user-adaptive systems have emerged to customize the needs and desires of specific users. Accordingly to its definition, a user-adaptive system is an interactive system that adapts its behavior to individual users on the basis of processes of user model acquisition and application that involve some form of learning inference or decision making [13]. Such systems are a promising support in the actual information foraging tasks, and their designers should accommodate as many as possible of the surrounding factors. Hence, the system changes from a single static tool, into a dynamic and multi-dimensional process, which adapts to its users.

This thesis introduces a context-based adaptive visualization environment, which employs detailed models of the user's characteristics, the data collection particularities, the system capabilities and the visualization methods' properties. These models, together with a set of rules, are used by the adaptivity engine to select the most prominent visualization method in each particular visualization request. This visualization environment has been designed for use in the Historical Archive of the University of

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Athens, to support its users in their information retrieval tasks. In order to select the most prominent individual visualization methods to include into the visualization environment and formulate the rules for adaptation, existing visualization environments have been reviewed and the usability and effectiveness of a number of systems with regard to specific tasks and data collection attributes has been assessed through a series of experiments. Since the suggested methodology takes into account the characteristics of the users, the area of user profiles has been studied, and a methodology for user profile creation has been suggested.

The following sections will outline the thesis' main contribution areas and more specifically (a) the study of the characteristics that are of importance regarding the users' interaction with a system for information retrieval and the formulation of a methodology for user profile creation; (b) the study of the visualization techniques, their properties, and the circumstances under which each one is effective, including different user groups and tasks (c) the formulation of rules for expressing visualization environment suitability and an algorithm that combines the rules and context data to suggest a visualization environment for a particular situation, synthesizing thus an adaptive system and (d) the extension of the above algorithm to include personalization characteristics, taking into account the observed behaviour of the user within the system.

2 User characteristics and user profile creation methodology

User profiling is commonly employed nowadays to enhance usability as well as to support personalization, adaptivity and other user-centric features. In the framework of the present thesis, the user profile is represented by an ontology, which is a formal explicit description of a domain. In order to create this ontology, various user profile information models sourced from bibliography were taken into account, which later were enriched and specialized. Table 1 presents an overview of the proposed ontology upper level classes.

Table 1. User Profile Ontology Upper Level Classes

Class Name	Class Description
Person	Basic User Information like name, date of birth, e-mail
Characteristic	General user characteristics, like eye color, height, weight, etc.
Ability	User abilities and disabilities, both mental and physical
Living Conditions	Information relevant to the user's place of residence and house type.
Contact	Other persons, with whom the person is related, including relatives, friends, co-workers.
Preference	User preferences, for example "loves cats", "likes blue color" or "dislikes classical music"
Interest	User hobby or work-related interests. For example, "interested in sports", "interested in cooking"
Activity	User activities, hobby or work related. For example, "collects stamps" or "investigates the 4^{th} Crusade"
Education	User education issues, including for example university diplomas and languages
Profession	The user's profession
Expertise	Includes all kinds of expertise, like computer expertise
Thing	Living things or Non Living Things the user may posses or otherwise be related to, like a car, a house, a book or a pet

This ontology presents information that is mostly static and permanent. More dynamic characteristics like the current position of the user when moving are not included. The temporal aspect of some of the ontology classes has been taken into account however. The ontology allows the existence of multiple instances of classes that represent characteristics that may change with the passage of time, like living conditions for example.

3 Existing visualization environments: Properties and efficiency assessment

A great variety of different visualization methods has been applied in different domains, such as digital libraries, file management systems, web pages etc. These methods are grouped according to the way they represent information in the following categories:

- Indented List
- Node-link diagrams and trees
- Zoomable interfaces
- Space-filling techniques
- Focus+Context and Distortion
- 3D metaphors

More specific features which are hosted in a visualization method include:

- User-adaptive techniques
- Color coding
- Document grouping

One or more of the above features may be included in a single visualization method, which ever the visualization method category in which it may belong. Each method, having its own set of features and functionalities, has advantages and disadvantages and may accommodate more or less effectively different tasks.

An experimental study was conducted in order to study the effectiveness of these visualization techniques, not only in completing different tasks, but also as far as the user's cognitive model and his/her personal estimation for the whole environment. Six different file management systems were selected, each using a different set of the above features and techniques. 30 volunteers, 15 male and 15 female participated in this study. They all differed in their computer experience, their age (ranging from 18 to 45) and their educational background. They all had interacted before with a file manager in order to organize their personal files, but none of them had even seen again any of the six selected visualization methods. The participants were asked to complete, first, a set of tasks concerning file management activities, then a set of cognitive tasks and last a set of evaluations on the visualizations they had interacted with. The researcher recorded the effectiveness (completion times) and the user's comments, analyzed them and drew conclusions.

The main set of tasks consisted of a number of file management tasks, for which the participants had to investigate the answer interacting with the visualization environment. The researcher recorded user's completion times together with user's comments on their interaction. These measures were analyzed and statistical methods were applied in order to extract statistical significance. One of the most prominent conclusions was the fact that zoomable technique was found to be the most effective visualization technique as it consist the most familiar visualization method. Users showed the lowest completion times when interacting with this category of visualizations, and they felt most satisfied, as they spent little time in order to get familiar to the environment. On the contrary, visualization techniques more unfamiliar to the participants showed statistically significantly high scores in completion times, as they didn't know at any time how to access the information needed. However, the results from the evaluation tasks showed that the familiar techniques were characterized as boring and ordinary, receiving a rather mediocre score in aesthetical and pleasure's criteria. On the contrary, the visualization methods which applied a totally unfamiliar environment received high scores in the aforementioned criteria. These visualization methods were favoured by participants with high computer experience, whereas those having lower computer experience stated a preference in more familiar and simple visualization environments. All these factors were influenced by the fact that an intuitive environment satisfied the users, whereas a disorienting visualization method frustrated them. These remarks had significant impact in the total evaluation.

There were two kinds of cognitive tasks. In the first one the users' mental imprint was examined. This took place in two phases: users draw the hierarchy of folders and files they had visited, immediately after interacting with the first of the six file browsers and they repeated the same activity after two or three days, that is before interacting with the rest of the file browsers. Thus, short-term memory and long-term memory imprints were examined. In the second category of cognitive tasks, users were asked to locate a number of folders and files, recall the neibourhood of a visited folder and the hierarchy level of another visited folder, after having interacted with each of the six file browsers. Examination of the results of cognitive tasks, showed that more elaborated and unfamiliar visualization environments resulted in more elaborated cognitive schemes and more recalls, whereas, simple and familiar environments resulted in cognitive schemes which had a lot of errors and misplacements while participants could not recall items easily.

The results drawn from the experimental study, described above show that no single visualization method could ever be considered the best one, as its effectiveness depends on a set of various factors. Thus, depending on the current context, which is a group of different properties (user profile, visualization method, as well as task attributes), a different visualization method should be selected. The process of this selection is based on an algorithm, developed in order to collect the current task and calculate the candidate winners between a set of predefined visualization methods. In the next session this process is presented.

4 Adaptive system for visualization algorithm selection

A list of basic features of visualization systems is depicted in Table 2. 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 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. For the compilation of the properties list appearing in table 1, a number of bibliographic sources were consulted.

Table 2. Properties of visualization systems and respective property values

Number of dimensions	• 2 (PLAO, IVEE, …) • 2 ½ (Data Mountain, LookMark, …) • 3 (IVEE, Perspective Tunnel, Task Gallery, PLAO, …)
Metaphor	• Landscape (Information City, Vineta, …) • Book and Library (WebBook, virtual library, …) • Perspective Planes & Panels (Data Mountain, Lookmark, etc) • 3D Geometric Shapes (Inform. 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 (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 Term frequency	• - (File System Navigator, Harmony Information Landscape, …) • - (Tile bars, PRISE, Themescape, …)

Visualization Method Selection

The visualization method selection procedure matches properties from the user, system and collection contexts against the visualization system properties. This matching is enabled through a rule database, containing rules of 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 visualization system 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.

For compiling the rule database, and in particular for assigning scores to (*context-property, vis-method-property*) pairs, users and visualization system experts were interviewed. In these interviews, subjects were asked to state how helpful/hindering each context property was considered in their opinion for performing each type of visualization. The interview results along with published evaluation results of visualization systems 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 *PM*, 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 $vp \in PM$. 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 expressed in 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 *vp* is considered “neutral” for contexts having the property *cp*; thus, there is no need to use rules of the form *(cp, vp, 0)* to explicitly state property orthogonalities.

An issue that has been commented on by users in the scheme above is that it is extremely prone to selecting different methods for consecutive visualization requests, even though the gains (as quantified by the respective method scores) may be marginal. Since users have been found to prefer a more “stable” work environment, a provision has been added in the score calculation procedure, to increase the score for the currently used method by a value of 5. This adjustment effectively directs the algorithm to perform a visualization method switch only when considerable gains will be attained, favoring thus environment stability. The value of 5 is currently a “magic number”, but in the future it is planned to incorporate it into the user context, in the sense that some users have a stronger preference towards stable environments (thus a higher “bonus” value could be used), while other users are more “adventurous”, so small bonus values (or even no bonus at all) should be given to the current method, in order to pursue even marginal gains from visualization method switching.

5 Adding personalization characteristics to the adaptive system

The visualization method selection process described in the previous paragraphs 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 the previous section 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-method)

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; in presence of such rules, the visualization method selection procedure reduces the total score for the method (as 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-method, score)

is added to the dynamic user profile, where *score* is "1" or "-1", depending on which response was selected. Note 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 prominent visualization method in system context SC and collection context CC according to the following scheme:

- if a *(dislike, viz-method)* 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 that best matches the current context. The value of the similarity metric falls in the range [-10, 10], with -10 meaning "totally different contexts" and 10 meaning "exactly matching" ones. The similarity metric between *(sys-con, col-con)* and *(SC, CC)* is calculated as follows:
  1. the set of all rule context facts RCF = sys-con $\cup$ col-con and the set of all current context facts CCF = SC $\cup$ CC are computed, and the similarity metric is initialized to 0.
  2. $\forall$rcf$\in$RCF, it is checked if rcf$\in$CCF. If this condition is true, the similarity score is incremented by 1, otherwise the similarity score is decremented by 1. Note that each element of RCF (and CCF) fully represents all aspects of a context element, e.g. the elements *sysctx-display-3D* and *colctx-origin-dynamic* specify that a 3D display is used and that the collection has been formulated through a query, respectively. Therefore, if the element of RCF appears in CCF, the two contexts are identical regarding the particular context element; otherwise the contexts are different in the specific respect (and CCF would contain a different element, e.g. *sysctx-display-2D* or *colctx-origin-static*).
  3. Finally, the computed similarity score ss_{val} is normalized in the range [-10, 10] by dividing by the cardinality of RCF and multiplying by 10.

  Note that the context similarity computation procedure described above considers all context elements to be equally important, since any match (mismatch) contributes by 1 (-1) to the final result. Assigning different weights to context elements for the purposes of context similarity computation is an issue under investigation and will be incorporated in a future system release.

  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, 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 for 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. In this case, the visualization methods are listed in descending order of their scores; a small sample of each visualization is presented, allowing the user to get a preview of the method before it is selected. 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 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.

6 Conclusions

In this thesis we have suggested an intelligent user interaction environment for the search and retrieval of historical data. Such an environment is quote complex since it must take into account diverse data, such as the available visualization methods, the preferences and skills of the users, the characteristics of the document collection to be visualized, the available system resources as well as principles from the area of human-computer interaction. To this end, the thesis has (a) surveyed existing visualization environments and assessed their effectiveness regarding information retrieval tasks (b) suggested a representation for user profile data and proposed a methodology for capturing the user profile (c) elaborated on the design of an adaptive and personalized system for information visualization.

As part of future research, we are considering an evaluation of the adaptive and personalized system for information visualization by more users, so as to obtain statistically significant results; the inclusion of more tasks is also considered. The concept of the *cognitive footprint* that has emerged in our research will be also elaborated on, and it is projected that the results from this area can have direct application in educational systems. Finally, immersive environments, which have significantly different properties than non-immersive ones, will be studied for incorporation into the proposed adaptive system.

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