Visualization method effectiveness in ontology-based information retrieval tasks involving entity evolution

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***Abstract*—Incorporating digital tools in the business and scientific research workflows is at the moment an on-going process, challenging and demanding as every domain has its own needs in terms of data models and information retrieval methods. The information in some domains involves entity evolution, a characteristic that introduces additional tasks, such as finding all evolution stages of an entity, and poses additional requirements for the information retrieval process. In this paper we present a user study aiming to investigate the effectiveness of current ontology browsing and visualization methods for supporting users in tasks involving research on entity evolution.**

Keywords*—*Ontology with entity evolution, information retrieval, ontology visualization, user interfaces.

I. Introduction

The constantly increasing amount of digital information in the current era inevitably raises issues of management and, more importantly, search and retrieval. Huge archives and repositories with millions of items are being created and maintained by organizations and enterprises. Under such an abundance of digital content, it is all the more important the need for semantic data organization and indexing efforts to address the need of domain experts for efficient access to high quality information necessary for the professions and research.

Ontologies can be very useful to this end [1] [2], since They can form the focal point of integrating different archives and sources as well as a common point of access and information retrieval (IR). Within repositories that maintain large amounts of past (and possibly present) documents, an ontology may be used for recording historical information extracted from the repository documents. We call such an ontology, a *historical ontology*. Historical ontologies typically cover a large time span, and consequently it is expected that classes, instances and/or relationships between them that change with the passage of time. The ontology should be able to reflect the evolution of the real world entities, providing facilities for designating the time instants or periods for which each represented real-world state is valid. Similar issues can be traced in professional domains involving large archives with historical information, such as archives of news agencies [3]. At representation level, time-evolving information can be accommodated either via versioning [4] or the four-dimensional perdurantist approach [5], according to which each entity is considered to be an event and has a start and an end point, and can be seen as a "space-time worm", with the slices of the worm being temporal parts (time slices) of the entity. At IR level, users, in addition to the IR tasks they perform in "ordinary" repositories (i.e. repositories not involving evolution), need to be able to (a) locate and mentally link together "worm slices" corresponding to different phases the same entity and (b) follow links between "worm slices", exploring entity history.

In this paper, we present a user study focusing on the effectiveness of current ontology browsing and visualization methods, when these are used for supporting users in tasks involving IR over ontologies involving entity evolution. To this end, we have conducted an experiment involving 23 users, in which participants were asked to locate information in an ontology using four well-established ontology visualization paradigms. Through this experiment, we obtained both objective data (such as overall time taken and percentage of correct answers), as well as subjective data (likings and dislikes of users), which were analyzed and provided valuable insight regarding the effectiveness and sufficiency of existing ontology visualization paradigms.

The rest of the paper is organized as follows: section II presents related work, while section III provides details on the conducted experiment. Section IV presents the experiment findings and discusses issues related to the impact of the visualization employed to the effectiveness and result quality of the IR tasks. Finally section V concludes the paper and outlines future work.

II. Background and related work

Historical researchers are a user class that conducts research related to the history and evolution of entities, and would therefore benefit from efficient ways to present and manipulate information regarding evolution. In [6], it is reported that evolution-related queries (person biographies and histories of organizations) constitute the 42% of the query bulk posed to the Historical Archive of the University of Athens. Researchers thus could explore information recorded into ontologies using appropriate ontology visualization tools to locate the evolution-related information.

Journalists are another user category that searches within historical archives for information regarding the history and evolution of entities and/or domains [3]. Additionally, 20% of the participants stated that most interfaces cannot provide comfortable and effective navigation in the categorization and the material itself.

Recently, ontologies have been identified as a potential aid to IR tasks. [7] examines how ontologies can be optimally exploited during the IR process, while [8] proposes an IR system, coupled with an ontology-based scheme for the semi-automatic annotation of documents. In some areas, domain-specific ontologies have been developed to be used for enhancing IR, such as the ontology used in Textpresso [9].

To exploit the information present within ontologies, users need methods and tools to efficiently locate the information they need within ontologies, with the predominant methods being browsing and querying. While querying is a powerful method for IR, browsing is an indispensable part of IR that may not be easily substituted by keyword search. As [10] suggests, browsing in some cases is preferred to keyword search as it imparts a greater sense of control to the user. Furthermore, browsing may be especially useful when a user is not exactly sure what s/he is looking for or s/he attempts to grasp the general idea of a domain. There are educational implications in the use of an ontology as well (e.g. [11]), which need to be further explored, especially concerning the implications of browsing an ontology in the learning process. Browsing is typically associated with some form of visualization, which presents to the user the available information space (or part of it) and allows her to zoom in or out and move between nodes and areas. [12] reports that effective visualization can significantly improve the effectiveness of browsing.

A number of ontology visualizations have been developed that are being used in the context of ontology management tools or as IR aids in applications that employ ontologies. Some interesting ontology management tool surveys are available in the Protégé web pages [13], whereas in [14] a detailed presentation of existing ontology visualization methods may be found.

Insofar, ontology visualizations have not been extensively evaluated regarding their effects on IR tasks. Notably, [15] reports on ontology evaluation, but the measures employed concern only certain views of the ontology; however IR is a complex process, which cannot be easily synthesized by the these factors, and therefore needs to be evaluated as a whole.

In the area of evaluating ontology visualization as aids for IR, [20] presents preliminary results derived from a group of 14 users. While this study offers valuable insight, it has only limited application to the use of visualization for IR over ontologies involving evolution sinca (a) it only examines two IR tasks involving evolution and (b) the ontology used in this experiment is ineffective, in the sense that “worm-slices” are linked together through descriptive text in a comments slot, clearly under-utilizing the expressive power of the ontology and encumbering the IR process.

III. Experiment description

As already stated, the purpose of this experiment was to determine whether current ontology browsing/visualization methods are effective and sufficient for supporting users in tasks involving research on entity evolution. In order to assess these aspects, the experiment involves IR tasks in which the subjects were asked to find information about the evolution of entities. To accomplish this task, seven IR tasks were carried out by the subjects using four different ontology visualization techniques, representative of the four major ontology visualization groups presented in [14], namely indented list, zoomable, focus+context and node-link+tree. The rationale behind the inclusion of multiple visualization techniques was to ascertain that any problems or deficiencies were not due to the shortcomings of a particular visualization or tool, but were actually rooted to the nature of the tasks (i.e. relation to ontology evolution). As a by-product of analyzing the results from different visualization methods, we could gain insight as to which is the most prominent ontology visualization method to conduct research with, concerning entity evolution.

This section offers an overview of the performed evaluation, containing descriptions of the evaluation user group, the ontology used, the query types used for IR tasks using the ontology, the description of the evaluation sequence and the evaluation limitations.

A. Ontology Visualizations

The methods chosen for the evaluation are Protégé Class Browser [13], Jambalaya [16], TGVizTab [17] and OntoViz [18], which are representative of the ontology visualization groups presented in [14], respectively indented list, zoomable, focus+context and node-link+tree. The visualizations are implemented as Protégé [13] plugins. We note that these methods were created mostly for ontology editing and are directed to ontology designers and experts. It was decided to use them for this experiment as there are not up to now any methods designed specifically for the presentation of ontologies to non-expert users. For the needs of the experiment participants were trained in their usage, and a sub-set of the options offered by the methods was employed (cf. subsection III-D).

Class Browser [13] is a simple visualization technique that offers a Windows Explorer-like indented list view of the ontology. In this view, the is-a taxonomy of the ontology is represented as an indented list. It displays the class hierarchy, with lower-level nodes presented as a list under their parent and indented to its right. Classes with multiple inheritance are placed under all their parents (fig. 1). The lists of child nodes may be retracted or expanded at will, by clicking or double clicking on their parent. The instances of a selected class are displayed in a separate pane to the right of the Class Browser. A search utility is also available, but it only searches among instances already displayed in the Instance Browser pane. There is no visual representation of the role relations, which are only accessible through the class slots.

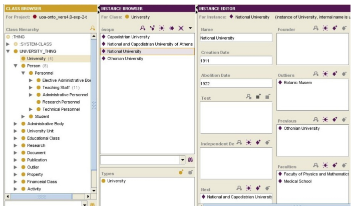

Fig. 1. The Protégé Class Browser.

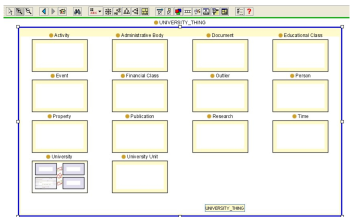

Fig. 2. The Jambalaya tab in Protégé.

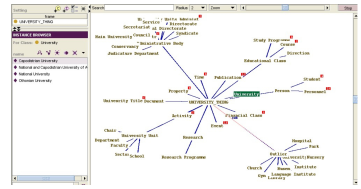

Fig. 3. The TGVizTab tab in Protégé.

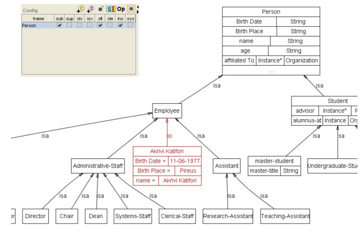

Fig. 4. Protégé OntoViz visualization (down-left) and configuration pane (upper-right).

Jambalaya [16] is a visualization plug-in for the Protégé ontology tool that uses the SHriMP (Simple Hierarchical Multi-Perspective) 2D visualization technique. SHriMP uses a nested graph view and the concept of nested interchangeable views, combined with geometric, fisheye and semantic zooming. According to SHriMP, nested nodes express the inheritance relations between the classes, as sub-classes are nested inside parent classes. Instances are also represented as nested nodes in their corresponding class in the graph. Instance nodes are distinguished from class ones by their color. Role relations between classes or instances are represented using directed arcs between the related nodes. Users may navigate in the ontology through this visualization in several ways: when a class or instance is selected by zooming on it, the SHriMP view focuses (using an animated focus technique) on the selected node; when a node is double–clicked, the view focuses on the clicked node and opens a form with the node information. The visualization tab offers an feature-rich "search" capabilitywhich, which allows users to specify the type of the searched item and also search within results.

TGVizTab (TouchGraph Visualization Tab) [17] implements the TouchGraph (http://www.touchgraph.com/) visualization technique. It uses a spring–layout technique where nodes repel one another, whereas the edges (links) attract them. This results in placing semantically similar nodes close to one another. This technique is especially interactive, as nodes move and adjust to the user commands, allowing also users to navigate, gradually making visible parts of the graph. The user may also expand, retract or hide nodes, rotate the graph and change the zoom level. Classes and instances are shown as nodes with different colors. The relations are represented as edges; is-a links are denoted as "sub" edges and role links have a label with the name of the relation they represent; this label is visible upon mouseover only, to avoid clutter. Fig. 3 presents the interface of TGVizTab. The ontology is also presented as a tree structure on the left (Class Panel). The Instances of a selected class may also be presented in the Instance browser on the left. Keyword search is available for locating classes and instances but it only works for what is already visible in the respective window. TGVizTab offers a holistic view of the ontology with all its features represented on the graph, but as ontology size increases, the view tends to become really cluttered, thus the completeness of the displayed information has to be traded-off with the display clarity.

OntoViz [18] is another Protégé [13] visualization plug-in using a simple 2D graph visualization method. The ontology is presented in a vertical tree layout with the capability for each class to present, apart from the name, its attributes and inheritance and role relations. Instance nodes are displayed in different color. It is possible for the user to choose which ontology features will be displayed, using the *Config Panel* (fig. 4). Right-clicking on the graph allows the user to zoom in or zoom out, through appropriate pop-up menu options. OntoViz contains a Class Browser pane at its left (c.f. fig. 4). This visualization is suitable for the presentation of small graphs, as it is quite clear and with no overlap. However, it is static, offering almost no interaction, and tends to clutter easily, so it is not very effective for browsing or visualization of large ontologies.

B. Evaluation User Group

The user group was composed of 16 men and 7 women. 17 of them were students, researchers or teaching staff in computer science-related departments, while 2 of them were students in humanity-related, 2 of them studied social sciences and the remaining two studied biology/food technology. All participants were chosen to have at least basic computer use expertise was selected; this was deemed necessary to be able to focus on the use of the visualizations, and not experience more basic problems with, e.g., the use of scrolling or selecting from pop-up menus. None of the experiment participants were experienced ontology designers. Eight claimed to understand to some extent the notion of an "ontology". Finally, five of them claimed the past use of ontology editors, but only to the extent of experimenting with the tool.

C. The Ontology Used

The ontology used throughout this experiment is the University of Athens Historical Archive (http://www.archive.uoa.gr/) Ontology, representing a portion of the institution's archive. The ontology was designed to present the current state of the University as well as contain information about its history. The ontology contains temporal information, which is in some cases incomplete and uncertain, which are typical features of information stored in archives. The creation process of the ontology is described in detail in [20].

The contains 205 classes, sparsely populated with instances, with 2/3 of the classes not having direct instances. The rest share 599 instances, unevenly distributed among them. The maximum depth of the is-a taxonomy tree is 5 classes, whereas the mean depth is 2-3 classes. Multiple inheritance is used with approximately 20 classes, with no class having more than 2 parents. More than half of the 176 distinct slots describe relations between classes, e.g. Professor "teaches at" Department.

D. Visualization Method Set-up

Before commencing the evaluation, we performed preliminary tests with a small user group (3 users, not included in the experiment user group), to decide on how aspects of visualization methods should be configured in the experiment.

Class Browser did not offer different presentation options, so it would be used as is. For the rest, we decided to introduce the users to a subset of the available functions.

For *Jambalaya*, the zoom-in/zoom-out tools, the Back, Forward and the Home button functions were introduced to the users, with the rest of the controls being hidden. The default presentation of Jambalaya was used along with the animated transition initiated when double-clicking on an instance. Although the relation links seemed to clutter the visualization, they were kept visible to further investigate if they aid or hinder browsing.

For *TGVizTab* we faced a major clutter problem due to role relationships, so the visualization was configured to show only the hierarchy (is-a) links and the instances appeared in the Instance Browser pane and not on the graph. The class panel was hidden, in order for the user to employ only the TouchGraph visualization features, and not resort to operations available through a panel similar to the Class Browser. The full range of the remaining options was presented to the user, namely zoom in, zoom out, graph redraw, distortion control, focusing on a node by double-clicking and the right-click context menu which allows the expansion and collapsing of sub-hierarchies.

Ontoviz, similarly to *TGVizTab* had major clutter problems due to role relationships, and therefore role relationships were hidden. During the experiment, participants had to select upper-level classes to visualize, and these classes were along with their subclasses and possibly their instances on the OntoViz visualization window (instances could be omitted for tasks involving only classes).

E. Ontology IR Task Types

In order to compile a set of tasks that would be representative of IR tasks within real-world archives, we were based on two resources. The first was the list of IR tasks a user may want to perform using an ontology visualization presented in [14] and the second was the list of queries made to the Historical Archive of the University of Athens (HA) for retrieving material. We performed an analysis of approximately 100 user queries made to the Historical Archive of the University of Athens and grouped them into categories according criteria, such as the number of different classes they entail, whether they are relevant to the ontology hierarchy or not, if they ask for the number of classes or instances with a common characteristic etc. Analysis showed that evolution-related queries either person biographies or institution/organization histories constituted the 42% of the queries (24% person biographies and 18% historical evolution of institutions/organizations) [6].

Besides the evolution-oriented IR tasks, we included a number of tasks not involving ontology evolution; this helped to create a baseline of performance for each ontology model and visualization method, against which the performance of subjects in evolution-related tasks could be measured. The IR tasks used in the experiment are described below.

Task T1 (not involving evolution). The user is given the type (class) of an instance and the value of an identifying slot, and is asked to retrieve the value of another slot of the particular instance - for example, "What is the year of birth of the Professor named Constantin Halatsis?".

Task T2 (not involving evolution). The user is given the description of a class and is asked to locate its direct subclasses (classes linked to the described one through an *isa* relationship). An example of such a task is: "What are the Central University Administration Bodies?"

Task T3 (not involving evolution). The user is given the description of an instance and is asked to retrieve the number of instances related to this instance through a relation with a "has-a" meaning. For example, "What is the number of sectors of the Department of Informatics and Telecommunications?". The user, after locating the given instance, has also to locate the appropriate slot that contains the instances requested and count them. The cardinality of the role relationship in this case is either 1:N or M:N.

Task T4 (involving evolution). The user is given two *entity state categories* and is asked to locate instances that evolved from the first state to the second in a specific time period. For example, "Who became Full Professor after X years from the time they s/he was elected as Associate Professor?" This task type, if not supported by a complex query mechanism, needs effort from the part of the user, since s/he has to look for the instances that satisfy the specific conditions, making calculations for the time periods.

Task T5 (involving evolution): Looking for a person Entity Timeline, i.e. for all information relevant to a specific person that has been recorded in the ontology. For example, "What are the biographical data present in the ontology related to a person with a specific name?" In this case, the user has to locate all the instances that may be relevant to a specific person and record the related information.

Tasks T6/7 Looking for an institution Entity Timeline, i.e. for all the information relevant to a specific institution, a faculty, museum, etc, that has been recorded in the ontology. For example, "What are the data present in the ontology related to a university department with a specific name?" In this case, the user has to locate all the instances that may be relevant to a specific institution and record the related information. The difference between T6 and T7 is that in T7 queries were selected to produce results that were instances of a single class only - e.g. a museum that was split to 3 new museums. In T6 queries yielded results that belonged to different classes, e.g. two Chairs were merged to form a Department which later became a Faculty. T7 was added to the second series of experiments in order to further evaluate the second ontology version.

F. Evaluation Procedure

Before the beginning of the evaluation, about one hour and twenty minutes was dedicated to explaining the concept of an ontology and its features and to instruct participants to the usage of the four techniques. Users were trained for about 15 minutes to using each method. To this end, a small ontology of 20 classes, 45 instances, and 46 slots was created to use for training, without introducing the experiment's ontology to the users. After the training period, users were asked to perform a set of tasks using each of the visualization methods, conducting thus a *within subjects* experiment, that would allow the comparative assessment of the visualizations. To promote result objectivity, the order of using visualizations was randomized and each specific query could not be posed more than once to any particular user, as the result would already be known to him/her.

Each set of IR tasks was composed of one task from each task type described in subsection III-E. The user had to find the answer and note it on the corresponding result form. There was a time limit of 10 minutes for each task and the participant was not allowed to backtrack to an earlier question and answer it if s/he came across the answer later in the duration of the experiment. After testing each method the user was asked to fill in a questionnaire, in order to record his/her impressions from using the method. After using all four methods s/he was asked to fill in a questionnaire with comparative questions related to the methods.

During the experiment the time users took to complete IR tasks was recorded. User failure to complete tasks was recorded as well, along with any comments or reactions and difficulties that the user may have had with certain tasks. Subjects were asked to think aloud in order to record any comments on the visualizations as well as the browsing methods applied to complete the tasks.

IV. Experiment results

In order to reach conclusions on the visualization methods' effectiveness and suitability for the selected tasks, and in particular the evolution-related ones, we recorded and analyzed information related to task completion times, correct answer percentages, user comments and behavior during the experiment and questionnaires, while we also analyzed user questionnaires.

Fig 5 illustrates the correct, incomplete, wrong and no answer percentages for the four visualization methods, regarding tasks (a) not involving evolution and (b) tasks involving evolution ("no answer" refers to cases where the subject aborted the task). Although none of the differences observed is statistically significant, observing the percentages, there are comments to be made.

Firstly, whereas in tasks not involving evolution the correct answer percentages are high for all the visualizations, for tasks that do involve evolution the correct answer percentages are very low. This suggests that the visualizations were effective to support browsing for locating simple pieces of information but they performed badly when the participant had to combine information in order to produce the answer. For T5, in particular, which included comparing dates between two different groups of "Person" instances, the mean percentage across all visualizations is about 21%, the lowest of all tasks.

All tasks except T4 had low "no answer" percentages (a mean value of less than 8% across all visualizations); task T4, on the other hand, was not completed by about the 54% of the users. This task proved to be the most frustrating for users. The cause for this high percentage is the fact that they were not sure on how to proceed, and most of them could not believe that they would have to compare, for example, the graduation date of all PhD students with the election dates of the Professors with the same name to see who was elected less than 10 years from his/her graduation. Due to user frustration, this task exhibited high "incomplete answer" percentages as well.

High incomplete answer percentages were noted for tasks T5, T6 and T7, which are related to entity evolution. It was commonplace for participants to browse until they found one or two instances related to the entity in question and then stop the search at that point, ignoring possible hints for more related instances. For example, when asked for information concerning the presence of "George Lepouras" in the University of Athens, they considered the search complete after locating the "Undergraduate Student" and "PhD Student" instances, ignoring the "Lecturer" instance. These particularly high percentages suggest that none of the visualizations was sufficient for representing entity evolution information in the ontology, although this information was modeled.

Fig. 6 presents the minimum, maximum and mean times taken to complete tasks the IR tasks (a) not involving evolution and (b) tasks involving evolution, using the four visualization techniques. As seen from the figure, the overall "winner" of the evaluation is Class Browser, the mean successful completion time of which was found considerably better that of the other tree visualizations. The

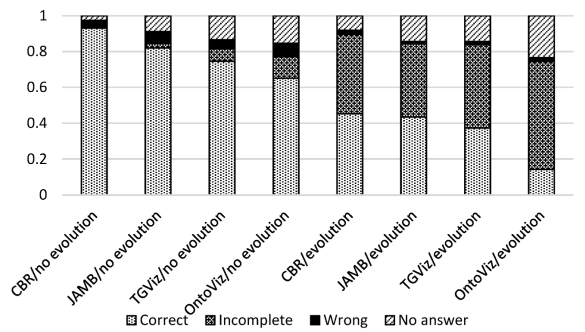

Fig. 5. Correct, incomplete, wrong and no answer percentages

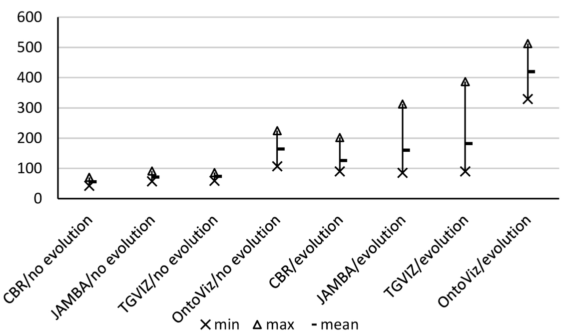

Fig. 6. Time taken for IR task completion

second position is shared by Jambalaya and TGVizTab, which have no substantial difference between them, and the last place is held by OntoViz, which performed significantly worse than the other three. However, we should not take these results into account as indicative for all node-link+tree ontology visualizations, as they are mostly due to interaction issues of the particular implementation, but rather use them as insight to possible shortcomings of this type of visualization. The results in the figure also indicate that while tasks not involving evolution are handled efficiently, the performance drops significantly when users cope with evolution-related tasks. This is an indication that IR tasks involving evolution are not adequately supported by current visualization techniques, and innovative methods, targeted to the specific type of tasks need to be developed.

V. Conclusions

In this work we presented the results of an experiment regarding the usage of ontology visualization methods for IR over ontologies which include entity evolution, with the aim to investigate the effectiveness of current ontology browsing and visualization methods for supporting users in IR tasks. The experiment has shown the limitations of existing ontology visualizations for supporting the representation of evolution; to this end, we are developing a new visualization method, based on the node-link+tree paradigm, which is enhanced with tools for representing evolution and at the same time attempts to overcome the interactivity shortcomings of OntoViz. This method will have to be tested, through a new evaluation.

Other lines of future work will include more targeted experiments with certain visualization features, such as the use of animation, as well as the study of combinations of visualizations and their effect in performance for different tasks.

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