Applications of Large Displays: Advancing User Support in Large Scale Ontology Alignment

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Abstract. Producing alignments of the highest quality requires 'humans in the loop', however, user involvement is currently one of the challenges for the ontology alignment community. Ontology alignment is a cognitively intensive task and could be efficiently supported by user interfaces encompassing well-designed visualizations and interaction techniques. This work investigates the application of large, high-resolution displays to improve users' cognitive support and identifies several promising directions for their application—improving ontologies' and alignments' navigation, supporting users' thinking process and collaboration.

1 Problem Statement

The growth of the ontology alignment area in the past ten years led to the development of many ontology alignment tools and a platform for their annual evaluation—OAEI[1]. In most cases ontology alignment systems apply fully automated approaches where an alignment, i.e., a set of mappings between two ontologies, is generated without any human intervention. Such approaches are only the first step in alignments generation [14] since advancing the algorithms did not lead to comparable improvements in the alignments' quality [18]. Involving users will lead to a greater improvement in the alignments' quality than developing more accurate algorithms [6]. Simulating user input by an (all-knowing) oracle led to the improvement of the alignments' quality in comparison to the fully automated approaches [9, 12, 22]. *Explanation of matching results* to users, fostering the *user involvement* in the process and *social and collaborative matching* are, however, still challenges for the community [31]. Another challenge is the evaluation of the quality and the effectiveness of user involvement [14, 15].

Graphical interfaces are essential to support users during ontology alignment, however, many systems do not provide such [31]. Furthermore, only about one third of the systems participating in the OAEI have any. Ontology alignment involves working simultaneously with at least two ontologies and often a large number of calculated mappings. This leads to issues related not only to the meaningful representation and navigation but also to the cognitive load during the alignment process. The demand for user interfaces is even more pressing given the trend towards growing size and complexity of the ontologies and the alignments.

Recently, with the development of technology and the associated cost reduction, large, high-resolution displays became available at affordable prices. It has been pointed

[1] http://oaei.ontologymatching.org/—Ontology Alignment Evaluation Initiative (OAEI)

out that 'when a display exceeds a certain size, it becomes qualitatively different'. A number of studies have shown improved performance and reduced cognitive load in an everyday office environment due to more peripheral awareness, glancing instead of windows switching to obtain additional information, flexibility in the organization of the space, etc. Environments where large displays are present are well-suited for activities involving several people where they can simultaneously work and discuss.

This work aims to improve the alignments' quality by addressing the challenge(s) of (collaborative) user involvement. It will design and develop user interfaces and corresponding visualization and interaction techniques by taking advantage of the latest technology developments. More specifically, it will investigate how to employ the extra space provided by large, high-resolution displays in order to improve navigation in the ontologies and alignments and provide a means to support the users' thinking process.

2 Relevancy

As indicated by the initial 3Vs of Big Data—volume, velocity and variety—the amount of data today is growing with unprecedented speed. Broadly speaking, ontology alignment addresses the problems of data and knowledge sharing and reuse by providing techniques for integrating different data sources; it provides a means for interoperability between semantically-enabled applications. Now, in the Big Data era, it provides techniques to turn the data from distributed, heterogeneous datasets into valuable knowledge for their owners. The user interfaces, that will result from this work, will support the 'humans in the loop' during the knowledge intensive alignment process.

Moreover, the potential benefits from improving the alignments' quality will spread over all domains and applications that demand alignments and more importantly to domains and settings where alignments of highest quality are vital. One example is the biomedical domain where compromises with the alignments' quality are unacceptable. It is one of the earliest adopters of Semantic Web techniques and there are already initiatives addressing the demand for mappings, e.g., some OAEI tracks, Bioportal[2] and recently the Pistoia Alliance[3] Ontology Mapping project.

In addition, showcasing the benefits from large displays will likely lead to their application in other ontology engineering areas as well.

3 Related Work

To the best of my knowledge there are no works that address ontology alignment in a large, high-resolution display setting. Ontology alignment systems with user interfaces do exist, some of the OAEI tools provide visual interfaces as well, but they only consider regular visualization and interaction settings, e.g., desktop and mouse. Tools' interfaces often resulted from the need to provide user input to matchers [15], and functionality and usability issues with them exist (recent reviews in [12, 20]). They are rarely theoretically grounded and not based on advances in cognitive theories (except [16]). Earlier evaluations can be found in [15, 16, 18, 24].

[2] http://bioportal.bioontology.org/—repository of biomedical ontologies

[3] http://www.pistoiaalliance.org/—a non-profit alliance of life science companies

This section presents work in connection to several aspects since there is no work considering ontology alignment in a large display setting. First, subsection 3.1 provides some considerations for ontology alignment and identifies opportunities for the application of large displays in its context—improving ontologies' and alignments' navigation, space to support users' thinking process and collaboration. Each of the following subsections (3.2, 3.3, 3.4) focuses on one of the opportunities and presents findings from relevant fields in support for it.

3.1 Ontology Alignment (some considerations)

Ontology alignment is a complex and challenging task imposing significant cognitive demands on the users [15, 16]. Users are most often involved in selecting matchers and configuring combination strategies, validating automatically generated mappings, etc. The alignment process usually involves the user exploring both (unfamiliar) ontologies in order to become familiar with them and their formal representations and to understand their modelers' view of the domain. Further, the user needs to explore the mappings computed by the tool's algorithms in order to determine their correctness and create mappings missed by the system. It is an inherently error-prone process due to different levels of users' domain and knowledge representation expertise, experience, human biases, misinterpretations, etc.

The tasks above demand extensive *navigation in both ontologies and their alignment*. Depending on their visual representation, navigation may involve panning, zooming, scrolling, collapsing/expanding nodes, etc. and could result in users getting lost and disoriented; disorientation was, indeed, reported by Protégé users in [32]. Interactive navigation and ontology exploration are discussed as part of a cognitive support framework for ontology alignment [16]. The navigation within the alignment was improved in a large schema mapping tool [29] but it is not clear how it impacted the understanding of the ontologies and alignments. At the ontology modeling field, navigation was outlined as one of the areas that demands cognitive support [13]. Navigation and related behaviors was studied in [11] and requirements for cognitive support were devised.

Navigating and exploring ontologies serves to inspect and compare mappings, concept definitions and contexts, etc. for various purposes, e.g., to decide if a mapping is correct or if there is a better representation of the relationship between two concepts. To do so the user switches between views and windows while holding and processing necessary information in working memory which has limited capacity and duration (3 ± 1 items and 10–15 sec. without rehearsal). Activities as above could effectively be supported by *extra display space* through simultaneously accommodating multiple (connected) representations to reduce the memory load. Decision making strategies involving comparisons are discussed in [16]. Other reasons for comparing and contrasting activities include revising previous decisions, their reasons and state of the process at that time, simulating, exploring and evaluating the consequences from a validation, identifying and resolving conflicts, etc. These tasks become even more important and information demanding when the alignment happens over a long period or in a collaborative setting. Exploration and comparison are also necessary for evaluating matchers' performance especially if no reference alignment is available and can also serve for the purposes of identifying potential errors [4]. Verification discussed for ontology modeling [13] is also relevant to ontology alignment.

(Large-scale) Ontology alignment, similarly to ontology development, is hardly a single person task and *social and collaborative matching* is one of the challenges identified in [31] and a requirement from [20]. It is unlikely that one person possesses the domain knowledge needed to map all parts of the ontologies. Several people working together can discuss doubtful mappings and potentially reduce errors in the alignment. There is, however, little work done in this direction.

3.2 Navigation in Digital Environments

Spatial navigation is a result of complex interaction of cognitive processes [36]. Navigation in digital information spaces in connection to humans' spatial abilities has been a subject of earlier studies outside of the context of large displays. In a number of studies participants with higher spatial abilities were more efficient in information seeking tasks in a large file system, an online environment, a modified browser, an online shopping database system, a hypermedia system, a command line interface. People with lower spatial abilities got lost in a hierarchical file system, completed fewer tasks and 'were hesitant to explore large numbers of categories'. Authors have suggested [7] that higher spatial abilities support the construction of better mental models of the system which are further employed while searching and navigating it. Differences in performance can be addressed by providing navigational aids, e.g., maps, that reduce the need for creating a mental model.

A significant part of the benefits provided by large displays are in connection to humans' spatial abilities. Large displays often replace virtual navigation by physical 'thus allowing the user to exploit embodied human abilities such as spatial awareness, proprioception, and spatial memory' [3]. Experiments in a virtual world [33, 34] compared a large, projected-wall display and a standard desktop display (with equivalent content). In the wall condition the users adopted more efficient cognitive strategies for egocentric tasks and performed better in path integration [34]; mental rotation, 3D navigational tasks, mental map formation and memory [33]. The effect of the display size on performance seemed independent of other influencing factors, e.g., interactivity and mental aid (e.g., landmarks). The performance for navigational tasks in large display conditions with more environmental cues (higher resolution or wider field of view) was improved for both males and females [10, 26]. Significant effect on display size and task complexity was shown in an abstract data manipulation task [25], and for low level visualization and navigation tasks, e.g., finding and comparing very detailed data [5].

3.3 Using *Space to Think* by *Using Vision to Think*

One promising application of display space is to use the 'space to think' [2] by 'using vision to think' [8]. Visual representations serve to offload work to the perceptual system and expand working memory storage and processing capacity [8]. High correlation between working memory capacity and general reasoning abilities in large-scale studies was demonstrated in [1], but it is not yet well understood if the storage or processing capabilities (or both) account for the performance differences. Both storage and processing capabilities are addressed by the extra space of large displays. Instead of views' switching, it could accommodate multiple representations simultaneously, thus reducing the memory load. In the field of software comprehension tools, two of the principles in [35] consider freeing working memory by employing artifacts from the environment and choose easier to comprehend (by the humans' perceptual system) representations.

Large displays provide more space for process and sensemaking [3]. A series of 11 data-analysis workshops conducted on a six-meter white board provided examples of the anticipated usage of additional space by domain experts in various domains [23] including ontology alignment—use the space for persistent views of the data; show multiple views side-by-side; spread data to enable easier selection and modification; support 'trail of thoughts', enable backtracking and exploration of possibilities by visually depicting earlier steps. Multiple coordinated views on a wall-sized display led to different quality of insights attributed to reducing the view switching distractions and staying longer in 'insight-generating mental states' [28]. In the context of ontology alignment, users can be supported during the comparison and contrasting activities by presenting information persistently (instead of keeping it in memory while switching between views) and offloading part of the processing to the perceptual systems (instead of the memory). Comparing shape and color of simple objects was faster and caused fewer errors when information was presented simultaneously instead of on different zoom levels [27] or views. Since the visits between two juxtaposed views are cheaper (in comparison to zooming) more visits were made (which could contribute for fewer errors) [27].

Additionally, multiple views allow for balancing the advantages and disadvantages of different visual representations [21]. For large, heterogeneous datasets presenting the different aspects of the data 'may benefit user cognition' [21] and, as also shown in the context of ontology alignment [17], is suitable for different tasks. Different representations of the same data influence task efficiency and complexity and could even affect decision-making strategies [37].

3.4 Collaboration

Large displays naturally support two behaviors observed in a collocated collaborative setting: territoriality—separating the space into personal, group, and storage space, and fluidly changing collaboration styles ranging from loosely coupled to closely coupled interaction. In contrast to desktop settings, they support several people working in parallel on different parts of the workspace by providing multiple simultaneous inputs and enough space to accommodate several (copies of) representations. Mutual awareness and background information have been identified as factors contributing to the success of collocated settings; they help in communication and coordination between people and are also supported by extra space. Recently, due to geographically distributed teams, mixed-presence settings have gained attention [30]. In such settings a shared workspace is created by connecting large remote displays where people interact with artefacts and can observe each other's actions as if they were working in a collocated setting. Some awareness mechanisms (hindered in a regular remote setting) such as territoriality and view orientation are supported in a mixed-presence setting due to the extra space [30].

4 Research Questions & Hypotheses

The research questions (R) and related hypotheses (H) explore different opportunities in which the extra space will lead to improvements in the alignments' quality and potentially speed up the ontology alignment process:

- **R1**: Are there benefits from applying large displays to ontology alignment for individual users and how to design and build such tools?
  - **R1.1**: Would the use of large displays help users in acquiring better understanding of the ontologies and alignments and how?
    H1.1: Users will acquire better and/or faster understanding of the ontologies and alignments due to improved navigation within them.
  - **R1.2**: Would the use of large displays support users during the ontology alignment process and how?
    H1.2: Externalizing and supporting the thinking process by simultaneously providing multiple (connected) views will allow users to offload some of the cognitive processes to the perceptual system thus reducing their cognitive load.
- **R2**: Are there benefits from applying large displays to ontology alignment in a collaborative setting and how to design and build such tools?
  H2: Collaboration in collocated and mixed-presence settings will be more efficiently supported due to the additional space.

5 Preliminary Results

Preliminary results in connection to the hypotheses above have not been obtained yet. Preliminary work to develop requirements for user support in large scale ontology alignment has started and consisted of user and literature evaluations of state-of-the-art systems [12, 20]. Other authors have conducted a number of workshops, including an alignment workshop, for studying interaction techniques for large displays [23]. Their study provides examples of how domain experts envision the usage of extra space for ontology alignment and an evidence for the practicability of H1.2.

6 Approach & Evaluation Plan

Further review of related literature will be performed to deepen my understanding in the areas covered by the hypotheses and to identify suitable visualization and interaction techniques. Depending on the hypothesis this literature will be selected from: navigation in complex digital environments in the context of software and knowledge engineering, schema matching, collaborative ontology engineering, design guidelines for collaborative environments, interaction techniques for large displays, etc. Cognitive task analysis or alternatively 'cheaper' cognitive walkthroughs with related/existing systems (in connection to the tasks and requirements identified in [16, 20]) will be conducted to envision places for introducing multiple views. This will result in the design and implementation of a user interface for an ontology alignment system taking advantage of the extra space available on a large, high-resolution display.

Conducting user studies with domain expert and novice users in both laboratory and everyday setting would be very beneficial during the design phase and it is necessary for evaluation of the resulting user interfaces. The experiments will necessarily cover at least the following conditions size(small, large) x interface(H1.1:with/without navigational aids; H1.2:with/without multiple views). A combination of measures will be used for evaluation—performance metrics such as response time and accuracy, think-aloud protocols, collecting activity logs and self-reported metrics (NASA-TLX often used for cognitive load and SUS for usability; secondary task response time for extraneous cognitive load). Precision, recall and F-measure will be used to measure the impact on the alignments' quality. Collaborative features could be evaluated with a heuristic evaluation for groupware. Depending on the resources, collaborative sessions and interviews with the sessions' participants could be conducted and analyzed.

7 Reflections

My previous work in the area of ontology alignment, e.g., [12, 19, 20], together with analysis of related work in the field have provided understanding of the issues during the process. To address them, a review of literature from a broad range of fields has been conducted starting from cognitive psychology basics, navigation in digital environments, software and knowledge engineering, collaborative environments design, etc. and several promising directions were identified in the hypotheses.

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