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VOAR : a configurable web-based environment for visualizing and manipulating multiple ontology alignments

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Abstract. Ontology matching is an active research area aiming at providing solutions to the ontology heterogeneity problem. While most efforts in the field are dedicated to the development of matching approaches, less has been done in terms of alignment visualization. However, providing ways for visualizing alignments is required in many tasks involving users in the process (alignment evaluation, validation, comparison, repairing, etc.). This paper presents a Web-based environment for visualizing, editing and evaluating multiple ontology alignments. Users can configure their environment choosing different visualization modes and creating different profiles. They can apply a set of operations on the alignments (filtering, merge, etc.) and evaluate them against a reference one, using classical compliance metrics. Ontology and alignment libraries allow for users storing and searching them in the system.

Keywords: Ontology alignment, ontology matching, ontology visualization

1. Introduction

Ontology matching is an essential task for the management of the semantic heterogeneity in open environments. Diverse matching approaches have been proposed in the literature [12], their systematic evaluation has been carried out over the last fifteen years in the context of the Ontology Alignment Evaluation Initiative (OAEI) campaigns [11]. While most efforts in the field are dedicated to the development of matching approaches, less has been done in terms of the alignments visualization. However, providing ways for visualizing alignments is required in many tasks involving users in the process (alignment evaluation, validation, comparison, consensus, repairing, etc.). As stated in [9], automatic generation of alignments should be viewed only as a first step towards a final alignment, with validation by one or more users being essential to ensure alignment quality. Visualizing tools play a key role in this process.

Most solutions for alignment visualization and manipulation are however limited to the visualization of single alignments and offer limited support to evaluation analyses. Some of them are provided as part of specific standalone matching systems [5,30], with few Web-based user interfaces [22,38] being available. Alternative solutions include Protegé plugins [31] or independent Web-based interfaces for manipulating and storing alignments with limited support for graphical visualization [8] or allowing the visualization of single alignments [18]. Other solutions are dedicated to visualizing alignments between different kinds of sources, as relational schemes and ontologies [36]. More recently, a standalone interactive visual environment which provides comparative exploration and evaluation of multiple ontology alignments at different level of detail has been introduced in the OAEI campaigns [19].

This paper presents VOAR 3.0 (**V**isual **O**ntology **A**lignment Envi**R**onment)[1], a configurable environment for manipulating multiple alignments. It provides an open Web-based environment that is not bound to any specific system and that offers a GUI for assisting users in the tasks of alignment visualization, manipulation, and evaluation. The major contribution of this version with respect to [35] is the possibility of choosing different visualization modes of multiple alignments, both at schema and instance levels, together with the possibility of storing and searching them. Users can configure their environment according to their needs and tasks, creating different profiles. The paper also presents a user evaluation of the tool.

Our proposal relies on observations from studies in the field and on a survey involving users of the domain. As stated in [15], *tool designers should consider combining multiple ontology visualization techniques that can engage users from different viewpoints yet are complementary to one another*. This statement is corroborated in the study from [24], finding that *there is not one specific method that seems to be the most appropriate for all applications and, consequently, a viable solution would be to provide the user with several visualizations*. Complementary to these findings, and more specifically dedicated to ontology alignment visualization, [17] affirm that *no single visual representation is capable of fulfilling all requirements*. With respect to the initial survey we carried out with the users before fully developing the tool (for sake of brevity we present the results from the second survey, carried out on the final version of the tool), they pointed out that *a tool has to provide different visualizations to balance for their advantages/disadvantages and they have to be suitable for different tasks, user experience and preferences*.

The rest of this paper is organized as follows. §2 introduces the ontology matching process. §3 discusses the related work in alignment visualization and manipulation environments. The functionalities of the proposed system are then presented in §4. The user feedback provided on the tool is discussed in §5. We conclude the paper discussing the limitations of the tool in §6 and presenting what is planned to be addressed in future work in §7.

[1]`http://voar.inf.pucrs.br/` (recorded video at `https://youtu.be/wq-yPBOFN_I`)

2. Background

Ontology matching is the process of finding correspondences between entities from different ontologies [13]. It usually takes as input two ontologies o and o' and determines as output an alignment A', i.e., a set of correspondence. A simple correspondence can be defined as follows:

[**Correspondence**] A correspondence is a tuple $<e,e',r,n>$, such that: e and e' are ontology entities (e.g., classes, properties, instances) of o and o$'$, respectively; r is a relation holding between two entities e and e' (for instance, *equivalence* ($\equiv$), *more general* ($\sqsupseteq$), *disjointness* ($\perp$), *overlapping* ($\sqcap$)); and n is a confidence measure number in the [0;1] range assigning a degree of the trust on the correspondence.

Different matching approaches have emerged from the literature. A review of them can be found in [23, 13]. While *terminological* methods lexically compare strings (tokens or n-grams) used in naming entities (or in the labels and comments concerning entities), *semantic* methods utilize model-theoretic semantics to determine whether or not a correspondence exists between two entities. Approaches may consider the *internal* ontological structure, such as the range of their properties (attributes and relations), their cardinality, and the transitivity and/or symmetry of their properties, or alternatively the *external* ontological structure, such as the position of the two entities within the ontological hierarchy. The instances (or extensions) of classes could also be compared using *extension*-based approaches. In addition, ontology matching systems rely not on a single approach and their combination relies on different strategies (e.g, from simple ones as average or weighted to learning the best combination of similarity metrics).

3. Related Work

Alignment visualization is closely related to the problem of ontology visualization. Early works have addressed the problem of ontology visualization (refer to [24,10] for surveys in the field). More recently, the visualization of Linked Open Data has received a growing attention [6,3,1] with dedicated workshops addressing the topic[2]. In the ontology matching field, visualization is seen as a key aspect in user involvement, alignment quality and alignment evaluation. We

[2]`http://voila2018.visualdataweb.org/`

can distinguish two main categories of solutions: those integrated to matching systems and those developed independently of a tool.

Most of the existing solutions fall in the first category, usually provided as part of specific standalone matching systems, such as AgreementMaker [5], COMA++ [2], YAM++ [29], S-Match [16] and OPTIMA [25]. Some versions of them address the problem of handling large ontologies, such as AgreementMaker [32], or still ProvenanceMatrix [7], which focuses on large but simpler structures as taxonomies. Few Web-based user interfaces have been provided, as the for LogMap [22] and Silk [38]. Alternative solutions include Protege plugins (e.g. PROMPT [31] and AlViz [26]). While the focus of these tools is the generation of alignments, in [20] the task of alignment debugging has been addressed.

Intermediary solutions include those for visualizing and manipulating alignments, as the Alignment Server [8] that offers a Web-based interface with the possibility of generating alignments from basic matching strategies (those available in the Alignment API) and manipulating alignments (filtering, inverting, and searching).

The second category of solutions, developed independently of a matching system, is less represented than the first one. An example is the AlignmentCube [19], a standalone interactive visual environment which provides comparative exploration and evaluation of multiple ontology alignments at different level of detail. This tool has been recently introduced as an evaluation support in the OAEI campaigns.

While all the above proposals focus on the visualization of simple alignments (i.e., involving single entities from each ontology), a Web-based ontology alignment tool proposed in [4] addresses the generation and visualization of complex correspondences. The tool suggests possible correspondences which are automatically recalculated as the alignment process progresses. However, there is no support for multiple alignments.

Other solutions are dedicated to visualizing alignments between different kinds of sources, as relational schemes and ontologies [37]; (semi-)structured data to their RDF representation [18]; or still DL-Lite ontology to a relational source database [27].

Summing up, while many solutions are provided as part of specific standalone matching systems, VOAR provides an open Web-based environment that is not bound to any specific system. It offers a GUI for assisting users in the tasks of multiple alignment visualization, manipulation, and evaluation. Close to ours, [2] and [8] offer a repository of ontologies and alignments and operators for comparing alignments such as compose, merge or compare, while [25] offers different visualization strategies. However, they are limited to the visualization of single alignments and offer limited support to evaluation. In that sense, [19] is close to ours, offering different strategies for multiple alignment visualization and comparison (a cube-oriented view). Differently from [4], VOAR is limited to the visualization of simple alignments and does not handle very large ontologies as in [32].

4. VOAR 3.0: Visual Ontology Alignment Environment

VOAR (**V**isual **O**ntology **A**lignment Envi**R**onment) is a Web-based environment for visualizing, editing and evaluating multiple ontology alignments. Users can configure their environment, choosing different visualization modes and creating different profiles. They can apply a set of operations on the alignments (filtering, merge, etc.) and evaluate them against a reference one, using classical compliance-based metrics. Ontology and alignment libraries allow for users storing and searching them in the system. It covers most of the requirements for interactive ontology alignment tools as discussed in [17] but focusing on alignment manipulation rather than on its automatic generation:

- presentation of (candidate) correspondences and their elements (relation, confidence)
- navigation and exploration of ontologies providing detailed information on their elements;
- overview of the alignment results for identification of regions with promising matching candidates;
- capability to adjust the level of detail for the viewed data (with different visualization strategies);
- filtering depending on correspondence features (confidence, relation, status of the correspondence (correct, incorrect, missing with respect to the provided reference alignment), etc.
- Confirming and rejecting correspondences, adding and removing correspondences manually;
- Saving and loading of users' changes on alignments.

Additionally, VOAR offers the following functionalities:

- visualizing multiple alignments together (better showing the parts of the ontologies which are covered for most alignments and those which are not, the consensus between alignments, etc.);
- quantitatively comparing alignments using classical measures as precision and recall.

VOAR has been developed on the top of the Alignment API[3] and the OWL API[4]. Its main modules are presented in the following.

The alignments displayed in the figures below have been generated by Lily, SANOM and XMap tools participating at OAEI 2018 in the Conference track, for the pair involving *conference*[5] and *ekaw*[6] ontologies.

4.1. Alignment storage and manipulation

In VOAR, alignments can either be created from scratch (by informing the URIs of the two ontologies to be aligned) or loaded from an external file (in the RDF format[7] adopted in the OAEI campaigns). Alignments and ontologies (RDFS or OWL) can be stored in the system. On top of storing ontologies and alignments, VOAR allows multiple alignments to be manipulated using a set of operations, for instance, *union* (resulting in the merge of alignments), *intersection* (where only correspondences occurring in all input alignments are kept), and *difference* (complement, where a subset of correspondences are removed from a given alignment) (Figure 1). Auxiliary operations involve *trimming* correspondences under a given threshold and *inverting* the alignment direction. These operations are available in the Alignment API and Alignment Server[8] for a pair of alignments and have been extended here.

4.2. Profiles

This module allows for users to configure the user interface and to create *profiles* with different configurations. For each profile (Figure 2), users can choose the kind of visualization approach to adopt (and that better fits their needs and task), as described below, the kinds of ontology entity to display (concepts, relations, instances), and the orientation of the windows (vertical or horizontal). Two windows can be set up and for each window, a different visualization strategy can be selected. A user can create several different *profiles* (Figure 3). This approach enables to complement weak points of one visualization with another parallel representation of the alignments, allowing the user to focus on the best aspects of each one.

4.3. Alignment visualization

This module allows for visualizing multiple alignments together, according to the *profiles* defined by the user. The alignments (and ontologies) can be visualized with the help of the following strategies:

Indented trees This common visualization strategy has the hierarchy of the ontologies presented as hierarchical trees (left of Figure 5). Relations and instances are presented at a level below in the class hierarchy, differentiated from subclasses by icons provided for each entity type (Figure 4). Correspondences are shown as lines connecting the two involved entities, and correspondences information, such as confidence and type, are displayed above the lines. In order to better identify the alignment that contains a given correspondence, when facing multiple alignments in the representation, a color is assigned to each alignment (this color is defined when creating the corresponding alignment).

According to [24] this way of visualizing the ontologies is familiar and intuitive for users with different levels of expertise, due to its similarity to a program to explore files and directories. However, it suffers from some limitations as it may not be very useful in tasks such as identifying the depth of the hierarchy, searching nodes with many children and identification of sibling nodes. This strategy is commonly adopted by matching tools, such as COMA++ [2], YAM++ [30], PROMPT [31], S-Match [16] and AgreementMaker [5].

Graphs With this strategy, each ontology is given a different neutral color, and each entity type is represented in a different shape (ellipses for classes, circles for properties and squares for instances) facilitating their identification by the user (since it lacks a hierarchical structure and everything is a node) (right of Figure 5). In order to discern affiliation between entities (e.g. classes to instances) from correspondences, the same logic of color per alignment from indented

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[3] `http://alignapi.gforge.inria.fr`
[4] `http://owlapi.sourceforge.net/`
[5] `http://oaei.ontologymatching.org/2018/conference/data/Conference.owl`
[6] `http://oaei.ontologymatching.org/2018/conference/data/ekaw.owl`
[7] `http://alignapi.gforge.inria.fr/format.html`
[8] `http://alignapi.gforge.inria.fr/server.html`

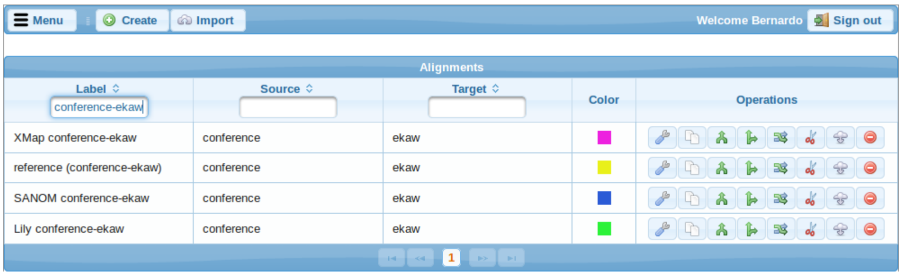


Fig. 1. Alignment manipulation interface.

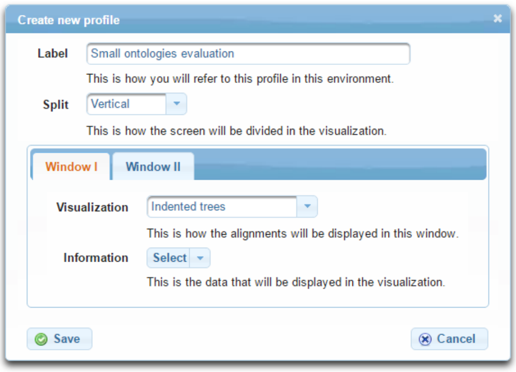


Fig. 2. Profile creation/edition on the VOAR system

trees is used to draw the links. In this way, correspondences are represented as a link between nodes, using the alignment color from the library. In order to facilitate the navigation, the user can move through the view of the graph and zoom in/out, focusing on a particular part or in the overview. We chose this strategy as it offer a complete overview of the alignments and involved entities, since it can connect all entities, and better represent multiple inheritance. OPTIMA [25] applies a graph-based visualization.

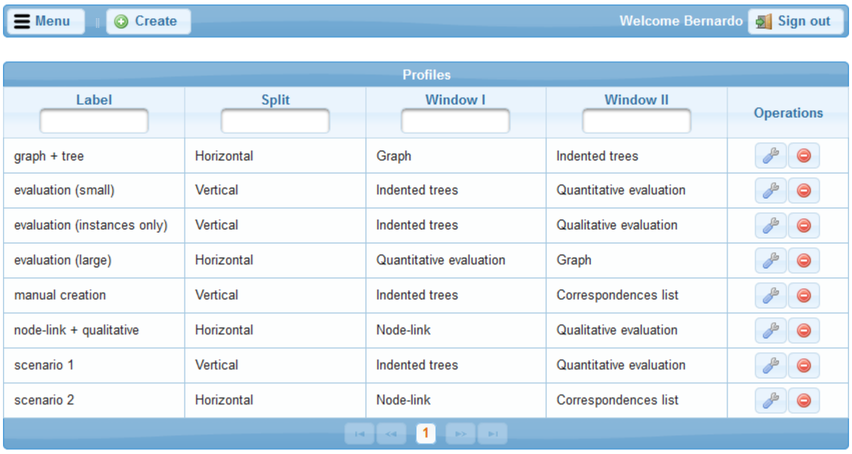
With respect to indented trees and graphs, a usability study has been conducted in [15] with an emphasis on the effectiveness, efficiency, workload and satisfaction of these techniques for the task of alignment evaluation. Their findings point out that:

– while the indented tree visualization is more organized and familiar to novice users, subjects found the graph visualization to be more controllable and intuitive without visual redundancy, particularly for ontologies with multiple inheritance;
– when ontologies are smaller and have a simpler structure, users are likely to achieve the same level of success regardless of the specific visualization used. However, given more complex ontologies, the indented tree is more effective;
– users are likely to be more successful at activities that concern the evaluation of existing alignments using indented trees, but more successful at activities that involve creating new correspondences using graphs. This finding suggests that the indented tree visualization is more suitable for list checking activities, and the graph visualization is more suitable for overviews.

Node-link Similar to the graph visualization, entities as nodes in the graph are displayed (left of Figure 6). The representations of entities by shape, correspondences by alignment color and correspondences data on over the link are maintained. Although it helps in the display of the ontologies structure, the connections that represent correspondences tend to make the representation overloaded in certain points. This type of visualization makes it easy to analyze the overall structure of the ontology, its depth and length. As for graphs, the limitation of this approach is the view for larger ontologies, given the necessary space on the screen to view each ontology entity. In [33], the authors point out that the side where the tree root is located have an inefficient use of screen space displayed, while the other side ends up visually charged. An examples of matching tool implementing this kind of strategy is OPTIMA [25].

Correspondences list Instead of graphically displaying the alignment and ontologies, this visualization lists the correspondences of each chosen alignment (right of Figure 6). This type of visualization is adopted by some tools, like Silk [38].

In VOAR, the user can chose the most appropriated strategy according to its preferences and task (creation or evaluation of alignments, for instance). As each visualization strategy focuses or facilitates the display of a specific set of ontology elements (classes, instances, relations, etc.) or perspective, the user can select the one most suitable to the kind of task to be performed (overview on the alignments, focusing on specific parts



Label	Split	Window I	Window II	Operations
graph + tree	Horizontal	Graph	Indented trees	
evaluation (small)	Vertical	Indented trees	Quantitative evaluation	
evaluation (instances only)	Vertical	Indented trees	Qualitative evaluation	
evaluation (large)	Horizontal	Quantitative evaluation	Graph	
manual creation	Vertical	Indented trees	Correspondences list	
node-link + qualitative	Horizontal	Node-link	Qualitative evaluation	
scenario 1	Vertical	Indented trees	Quantitative evaluation	
scenario 2	Horizontal	Node-link	Correspondences list	

Fig. 3. List of user profiles.

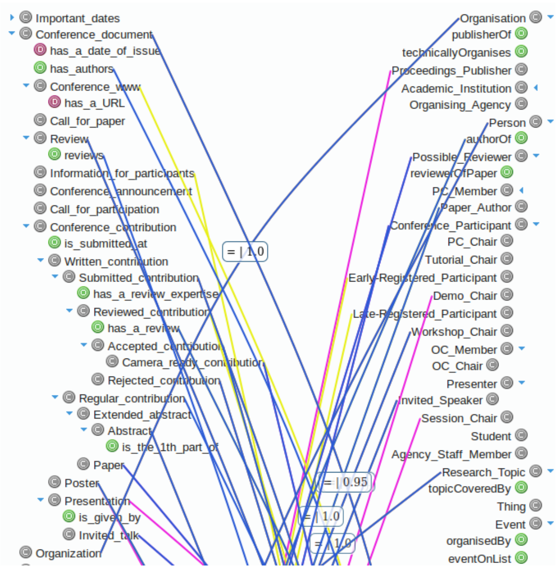


Fig. 4. Different types of ontology entities in an indented tree (instances being represented by a 'I' and object and data properties by a 'O' and 'D', respectively).

of the ontologies, analyzing the pairs of entities appearing in most alignments, etc.).

Users are also able to configure the properties of the correspondences to be shown (e.g., kind of relation and confidence) and apply filters on those properties in order to visualize a subset of correspondences. Allowing the users to choose the most adequate visualization for his/her working alignments, the ontologies involved (considering the size, number of relations, etc.) or even individual preferences.

4.4. *Correspondence editing*

As part of the possible *visualizations* to be selected, VOAR allows for manipulating the correspondences of an alignment. They can be added, suppressed or edited (e.g, modifying the kind of relation or confidence) (rigth of Figure 6). Users can select specific ontology entities for visualizing the correspondences involving them. They can also filter out the entities whose naming and annotations (labels, comments) correspond to a criterion.

4.5. *Alignment evaluation*

Users can compare multiple alignments with respect to a reference, using precision, recall, and F-measure (bottom of Figure 7). The implementations available in the Alignment API have been used for computing those measures. VOAR allows the visualization of the results in a tabular view and displays the status of each correspondence (correct, incorrect, missing) in the given alignment (top of Figure 7).

5. User feedback

In order to evaluate the tool, users with different levels of expertise in alignment generation and evaluation were invited to answer a survey. This survey was designed as an online questionnaire, with seven questions divided in two sets. In the first set, respondents were asked to rate the proposed solution regarding technical conditions that it should help to handle (multiple profiles, necessity of different views, se-

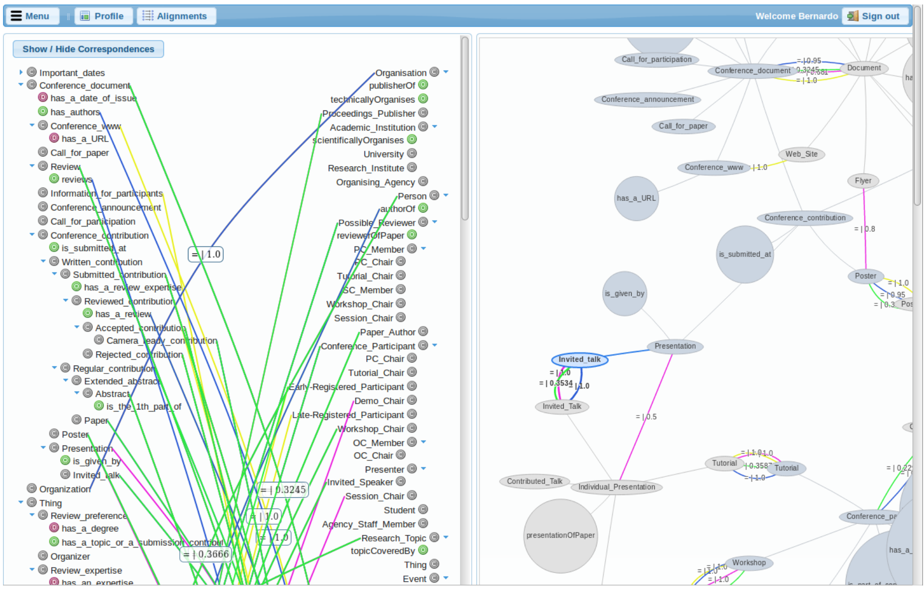


Fig. 5. Visualization of multiple alignments using intended trees (left) and graph (right).

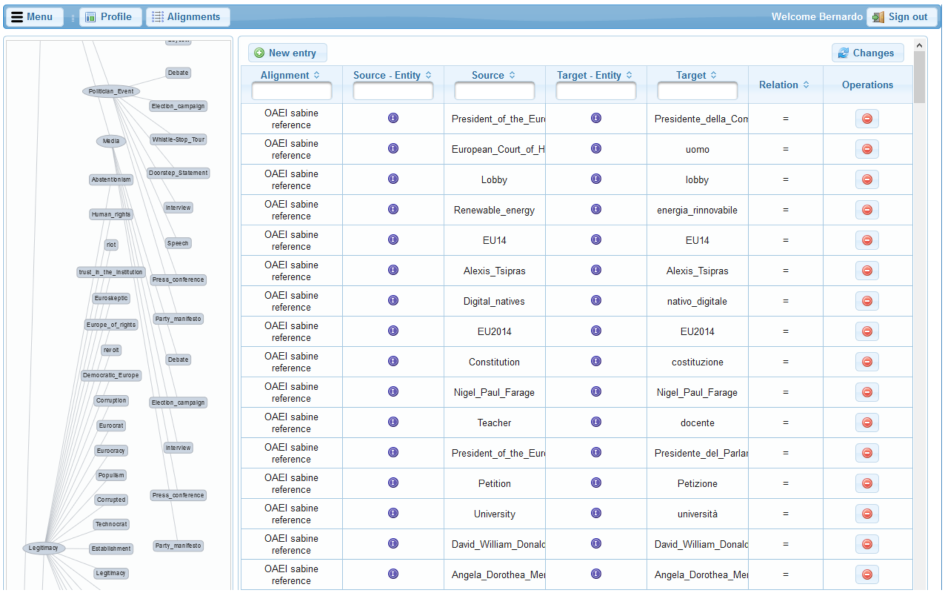


Fig. 6. Visualization of multiple alignments using node-link (left) and correspondences list (right).

lection of only relevant elements, etc.). In the second set, users were asked to state whether they agreed or disagreed with a set of general evaluation statements regarding the VOAR environment model. Answers were based on a Likert scale. At the end of the questionnaire, an open-ended question allowed the user to provide final feedback. A video demonstrating the system and users identifiers for accessing the tool for freely exploiting were made available. The survey received 10 responses (70 invitations were sent and the survey link was posted in a dedicated group at LinkedIn[9]). A period of 30 days was given for the

[9] https://www.linkedin.com/groups/3608066/, post https://www.linkedin.com/feed/update/urn:li:activity:6144128360638406657

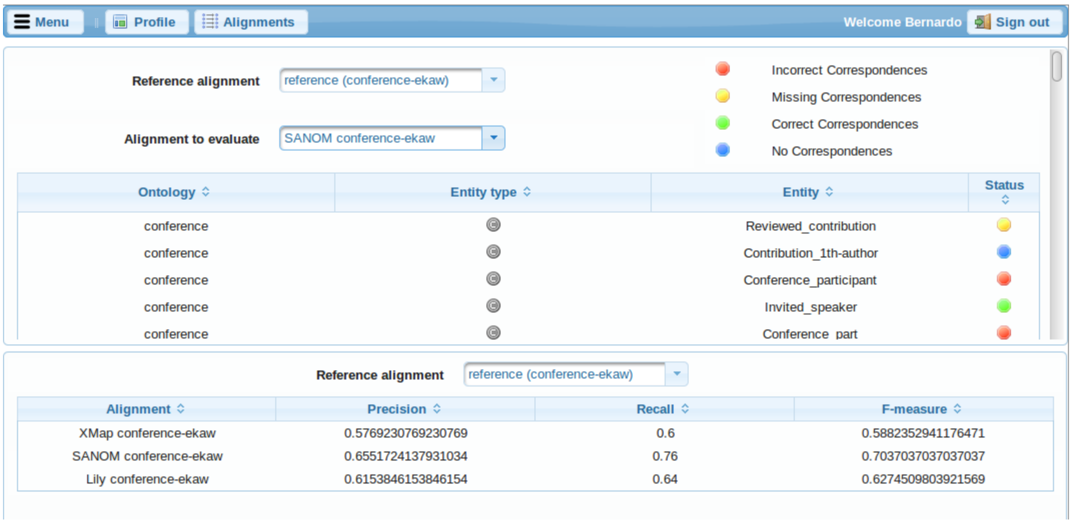


Fig. 7. Visualization of correspondences and their status (top) and evaluation results (bottom).

users to fill in the questionnaire. Regarding expertise with ontologies/alignments, 33% of the users classified themselves as 'intermediate' and 67% as 'expert'.

Overall, a quite positive evaluation on the system was reported. With respect to the first set of questions, the results are presented in Figure 8. These results suggest that the proposed approach is dealing well with the problems it intended to solve, with answers tending to the positive side. The analysis of each question is commented below:

– **Use of multiple visualizations (indented tree, graphs, etc.) in order to facilitate the analysis of different scenarios**: the users agreed that this seems to be an interesting solution to the problem of having to use multiple tools for different use cases. As reported by a respondent, improvements still could be made to make extensions possible as plugins, encouraging the community to create alternatives or their own visualizations.
– **Configuration of the ontology/alignment elements presented (instances, correspondences confidence, etc.) to adapt the visualization for what is important in a given task**: once again, the approach handles the issue for this scenario, with a margin for improvement. As pointed by a respondent, maybe more ontology information could be added to the visualizations, for instance restrictions.
– **Configuration of profiles to handle preferences according to ontology/alignment characteristics (kind of ontology entities, correspondence information)**: even being evaluated mainly as handling the issue well, some improvements and extensions might be considered, such as more visualizations or changes on what could be configurable.
– **Configuration of profiles to handle preferences according to the tasks being performed (creation, manipulation, evaluation, etc.)**: the proposal of configuring multiple profiles in order to achieve a visualization that fit what is necessary handles the issue very well. Since no approach in the state-of-the-art is known to provide such a variety of visualization strategies, this was the response with the highest rate in the evaluation.

The second set of questions approached more general questions, not related only to profiles. Like the first set, most answers stated that the solution helped in the exposed scenarios (Figure 9):

– **The adaptive approach in the model helps to minimize or solves particular problems with visualizations**: the idea of having alternative representations for the alignments as well accepted. Probably with the addition of more options, it will be even better/easier to find the complement for each visualization in specific scenarios.
– **The proposed approach helps to better analyze multiple alignments together**: this statement was mainly evaluated as positive, meaning that the purpose of enabling users to work with multiple alignments was successfully achieved. Some aspects might need improvement, for instance,

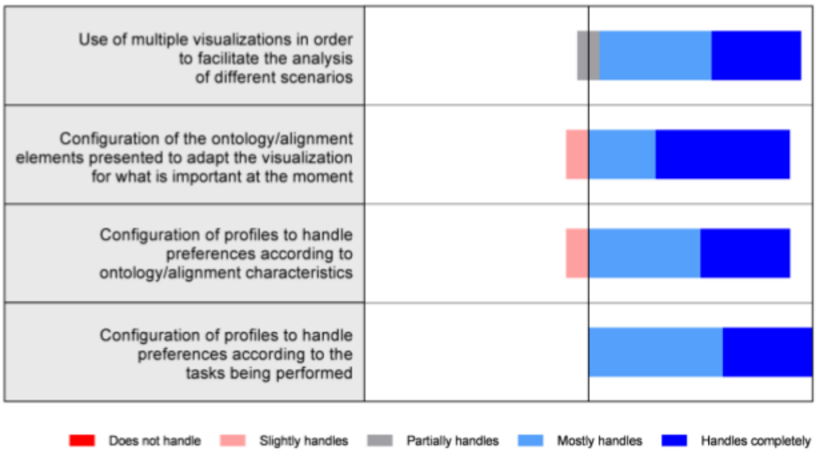


Fig. 8. Overall evaluation of VOAR with respect to the issues it is intended to address.

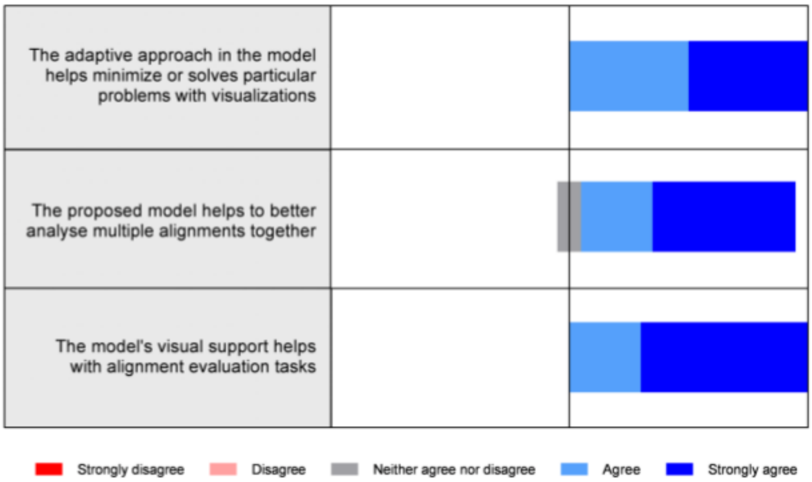


Fig. 9. VOAR evaluation on general topics.

the visualization sometimes presents overlapping correspondences from different alignments (i.e., different matchers generating the same correspondence). This should be better highlight in the visualisation strategies.

– **The approach's visual support helps with alignment evaluation tasks**: since many users perform evaluation tasks manually and without tools, the results being all positives on the support provided for these tasks reaffirm the value of a visual and dynamic way to work with evaluations.

6. Availability, limitations and impact

VOAR is available online and can be found at `voar.inf.pucrs.br`. Users are required to register in order to obtain an account.

In what concerns its limitations, dealing with large ontologies is certainly one of the major limitation of the tool. Another point is the visualization of a high number of alignments together. This has to be further investigated in terms of the visualization strategies as well (for instance, indented trees may offer in this case a unreadable and charged visualization if dealing with a high number of alignments). Furthermore, we do not made exhaustive tests involving more than 20 users using the system at the same time and users have at most

200MB of storage space for storing their ontologies and alignments.

With respect to the usage of the tool, it has been successfully used in master courses introducing the task of ontology matching and evaluation. While the tool may not be suitable for evaluating a high number of alignments (as required, for instance, at the scale of the OAEI campaigns), it can be a valuable resource both for beginners to analyze and manipulate (create, edit, evaluate) alignments and for more experimented user to evaluate alignments in a qualitative way.

7. Conclusion and future work

The lack of visual resources to work with multiple alignments and the need of more task-oriented visualization approaches demand a more versatile and configurable visualization tool. The tool we present in this paper results from the analysis of the state-of-the-art, findings from studies in the field [15,17,24], and opinions from users collected in a survey [34]. The tool offers the ability to manipulate, evaluate and visualize multiple alignments in several graphical ways. In order to present the most relevant information using suitable visualization techniques, users can configure “profiles”, structures that determine visualizations and what kinds of data to be displayed on it. Alternative profiles allow to adequate the most suitable presentation for different tasks. The possibility of selecting multiple visualizations and what information to display was not fully seen in previous approaches. Hence, the proposed approach stands out in the state-of-the-art not only by providing unique features, such as the ability to configure profiles, but also by unifying some features that are poorly explored, or given only in specific tools. Most tools provides only one type of visualization to display one alignment. Since multiple alignments are not common, operations over alignments are almost not present also.

The results obtained in the user evaluation provided clues that the approach contributes to the field. The evaluation of profiles configuration has shown that some improvements could be done to contemplate more scenarios. Original aspects of the approach, such as the use of one visualization to mitigate the problems of another and the use of multiple alignments to improve the analysis in tasks were considered by users as being resolved.

This work can be improved in different ways. We plan to investigate further usability aspects as in [14] (i.e., by having users performing specific tasks using the tool). We plan as well to deal with the scalability terms of large ontologies and alignments [28] and to evaluate how it satisfies a set of requirements [21] for user support in large-scale matching. We intend also to consider comparative evaluation of multiple alignments without a reference one, as reference alignments are not always available. Besides, we plan to work on collaborative aspects and on the visualization of complex and holistic alignments.

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