VOWLMap: Graph-based Ontology Alignment Visualization and Editing ⋆

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Abstract. Manual validation of automated ontology alignments remains essential to ensure their quality. However, few alignment systems feature user interfaces enabling alignment visualization, validation and editing, and those that do, support a limited number of requirements.
We developed VOWLMap—an extension for the standalone web application, WebVOWL—for visualizing, editing, and validating ontology alignments. WebVOWL implements the Visual Notation for OWL Ontologies (VOWL) which defines a visual representation for most language constructs of OWL. We extended VOWL to support graphical representations of alignments and restructured WebVOWL to load and visualize alignments. VOWLMap employs modularization techniques to facilitate the visualization of large alignments while maintaining the context of each individual mapping, and supports diverse interaction mechanisms, including direct interaction with and editing of graph representations.
We conducted a user study to collect feedback on VOWLMap, using as tasks the validation of alignments from the biomedical and conference domains.

Keywords: Ontology Alignment · Ontology Matching · Alignment Visualization

1 Introduction

Ontology alignment (or matching) is a solution to the semantic heterogeneity problem, as it establishes relations between entities of related ontologies, enabling interoperability [14]. This is critical due to the growing traction of ontologies and knowledge graphs as solutions for information management, which has led to their widespread but uncoordinated development.

Several ontology alignment algorithms and systems have been proposed over the last two decades, but for the most part, alignment systems focus on automated approaches without human intervention [4, 14]. Due to the complexity of ontologies, automated alignments often contain erroneous mappings, and are seldom complete [12, 14]. User validation of ontology alignments is essential to overcome the limitations of automated algorithms, as users can remove or correct erroneous mappings, as well as add missing ones [7].

Given the size and complexity of ontologies and alignments, it has become clear that comprehensive and more interactive visualizations are key features for user involvement in alignment validation, as they enable a better understanding of the alignment and support the decision-making process. Nevertheless, few alignment systems provide a user interface that supports alignment visualization, editing and navigation strategies, and even fewer provide the functionalities needed to make the task seamless for the user, such as interaction with the visualization or contextual information about the mappings [7].

According to [7], there are two aspects regarding user interfaces that are determinant to the process of alignment validation: alignment visualization and alignment interaction. Our main goal was to develop an interactive tool with an interface that provides visual support and functionalities to allow users to interact with and validate an alignment.

In this paper, we present VOWLMap[1], a tool for visualizing, validating and editing ontology alignments. VOWLMap extends the web application, WebVOWL [9] and its underlying visual notation (VOWL) [8] to the context of ontology alignment, offering an intuitive and comprehensive visualization that can be understood by users less familiar with ontology alignments. VOWLMap employs modularization techniques to facilitate the visualization of large alignments while maintaining the context of each individual mapping, and supports diverse interaction mechanisms, including direct interaction with and editing of graph representations.

2 Related Work

Ontology alignment visualizations can usually be divided into two visual paradigms: trees and graphs [4].

Under the first paradigm, ontologies are usually displayed side by side as indented trees—providing an intuitive representation of the hierarchy—and mappings are typically represented as lines connecting the corresponding nodes. Several ontology matching systems implement tree visualizations, including AgreementMaker [2] and COMA 3.0 Community Edition [10].

Under the second paradigm, systems that implement graph visualizations typically offer two views of an alignment: a list view spanning the whole alignment, and a graph view corresponding to a sub-graph of the alignment and ontologies. Examples include AgreementMakerLight [3], whose graph representation captures the neighborhood of a mapping, and YAM++ [1], that provides independent graph visualizations for the entities in a mapping.

Orthogonally, Ivanova et al. have focused on the visual exploration and evaluation of multiple ontology alignments. They proposed an interactive visualization interface to simultaneous explore and evaluate multiple alignments at different levels of granularity [5].

Visualizing ontology alignments requires first and foremost visualizing ontologies, since they usually dwarf alignments in volume of information and complexity. Moreover, two ontologies plus their alignment can be seen essentially as a larger ontology.

[1] Available at https://github.com/liseda-lab/VOWLMap

The Visual Notation for OWL Ontologies (VOWL) [8] is a visual language for user-oriented representation of ontologies that aims to help users intuitively understand ontology semantics. VOWL defines a set of graphical primitives and a color scheme that express specific attributes for most language constructs of OWL.

WebVOWL [9] implements VOWL as a standalone web application for interactive visualization of ontologies. It defines a JSON schema into which OWL ontologies need to be converted, which can be performed using OWL2VOWL, a Java-based converter deployed alongside WebVOWL. WebVOWL renders the graphical elements according to the VOWL specifications in a dynamic force-directed graph layout, using the JavaScript library D3. It implements basic interaction techniques such as zoom, pan and drag and drop. A sidebar displays details on a selected entity on the graph, along with other information, such as metadata, description, and metrics. Users can filter the visualization to reduce the size of the graph, based on property types or node degree. WebVOWL also supports text-based search and selecting a matching entity locates it and highlights it in the graph. In the experimental editing mode it is possible to create, edit and delete elements. Finally, the visualization can be saved as an SVG image or the ontology can be exported in JSON format.

3 VOWLMap

3.1 Methodology

Our approach to develop VOWLMap began with an analysis of the requirements described in [6, 7] and a selection of target requirements, followed by an assessment of existing development and visualization options. The success of Javascript-based visualization for complex data afforded by d3.js led us in the direction of a browser-based architecture, which facilitates use by precluding the need for software installation. After investigating existing browser-based ontology visualization systems, we reached the conclusion that WebVOWL matched our functional and technical requirements.

Regarding the categories of issues that affect alignment validation [7], we opted to target use cases where: (1) users are domain experts but may be ontology alignment novices; and (2) users are only involved after the alignment process, interacting with the alignment but not with the alignment system. We identified the following functional requirements:

- (R1) Loading of ontologies and corresponding alignment;
- (R2) Provision of alternative alignment views to support different tasks and user preferences;
- (R3) Support for visual information seeking tasks [13], i.e., (R3.1) overview (overview of the entire collection), (R3.2) zoom (zoom in or out on items of interest), (R3.3) filter (remove uninteresting elements from the visualization), (R3.4) details-on-demand (select element and obtain details), (R3.5) relate (view relationships among elements), (R3.6) history (keep track of actions) and (R3.7) extract (extraction of sub-sets of elements).
- (R4) Indication of mapping status, that is distinguishing between validated and candidate mappings;

(R5) Visualization of metadata, such as definitions and synonyms;
(R6) Visualization of a mapping context, i.e., showing the neighbourhood of the entities involved in the mapping, including nearby mappings;
(R7) Accepting and rejecting mappings;
(R8) Creating and refining mappings, i.e., adding new mappings manually or refining an existing mapping by altering the source or target entity.
(R9) Search, that is the ability to search for ontology entities by their labels;
(R10) Session support, that is accommodating interruptions when validating;
(R11) Exporting into different alignment formats.

3.2 VOWL Extension

Since the VOWL notation was conceived to represent a single ontology, we had to extend it to (1) distinguish between the two aligned ontologies (by representing them in different colors), and (2) represent mappings between them, with different colors for mappings with different (revision) status. We assigned the general light blue to the source ontology, and the dark blue to the target ontology (Figure 2). Each mapping is represented by a solid line linking the two mapped nodes, with arrowheads at both ends and a rectangle indicating the confidence score. To color these elements according to the mapping status, we add four new colors: dark green for *correct*, dark red for *incorrect*, medium yellow for *unsure* and medium gray for *unreviewed*.

The color scheme of VOWL already includes some variations of the colors mentioned above, which could potentially lead to misinterpretations between: (1) *incorrect* mappings in dark red and highlighting in VOWL red; (2) *unsure* mappings in medium yellow and datatype in VOWL yellow; (3) *unreviewed* mappings in medium gray and deprecated elements in VOWL light gray; and to a lesser extent (4) *correct* mappings in dark green and data properties in VOWL light green. However, we believe that the fact that mappings include a boxed label with the confidence score should enable a clear distinction between mappings and all these cases. Note also than under this extension, external elements to the ontology, represented by dark blue in VOWL, no longer have a representation in either the source or the target ontology.

3.3 Functionalities

WebVOWL supports some of the functional requirements we identified, however it does not support those directly related to alignment visualization and editing. VOWLMap extends WebVOWL with several features to support these processes.

Like WebVOWL, VOWLMap requires a JSON representation of the ontologies and alignment as input. To enable this, we developed a small Python-based tool that receives as input the JSON files of the two ontologies (previously converted using OWL2VOWL [9]) and an alignment RDF file. This tool merges these files into a single JSON file that includes all the information about the ontologies and the alignment, and that can be loaded by VOWLMap. To tackle the challenge of loading large ontologies, this tool only loads elements of the ontologies into the JSON file that are at a maximum distance of 3 edges of each mapping. This facilitates memory management and optimizes the

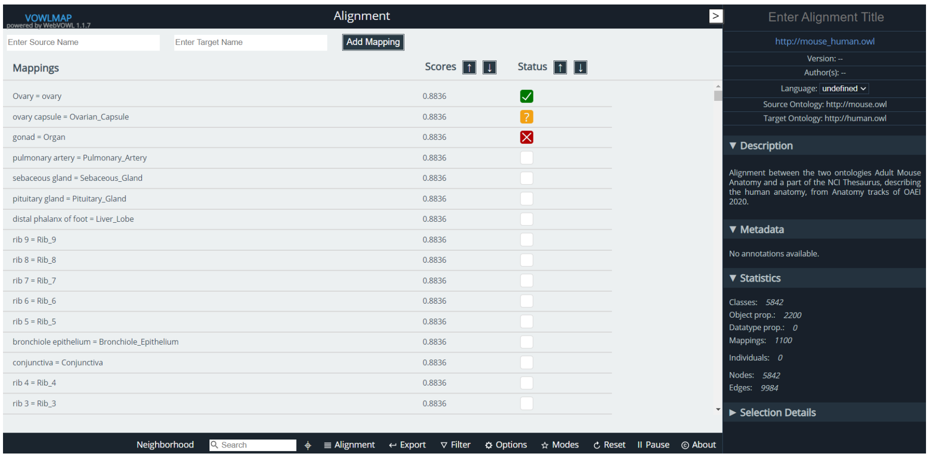

Fig. 1: VOWLMap alignment panel.

uploading time, by removing less relevant information, since the graph visualization only extends the neighborhood to a maximum of 3 edges.

VOWLMap provides two views of alignments: an alignment panel (Figure 1), and a graph visualization (Figure 2). Both views include a sidebar, listing information about the alignment, and a footer menu containing the visualization controls. The alignment panel is composed by a list of mappings, with their confidence score and status. In this panel, users can validate and create new mappings (Figure 1). By clicking a mapping from the list, a graph visualization for that mapping is generated, where both ontologies are represented in the same graph with different colors, and mappings are represented as double-edges arrows colored according to their status and labeled with their score. In addition to the selected mapping, all other mappings present in its neighborhood are shown.

Users can interact with the visualization: zoom in and out, pan the background and move elements around to adapt the force-directed layout. It is possible to change the characteristics of the visualization, such as class distance or datatype distance, and adjust the neighborhood (from zero to a maximum of three edges of distance). Moreover, VOWLMap provides the same filters as WebVOWL, that can be activated or deactivated at any time if users want to exclude or include information in the visualization or focus on certain aspects. In addition to searching for ontology entities, VOWLMap allows searching for a specific mapping in both views. When users enter the name of the one of the entities participating in the mapping in the search bar, a graph for that mapping is generated.

Users can visualize and edit a mapping status in both views. VOWLMap supports 4 values for the status - *unreviewed*, *correct*, *incorrect* and *unsure*. When users select a mapping in the graph, the sidebar provides information about the mapping, including a dropdown with its status where users can validate the mapping by selecting one of the four available options. For instance, Figure 2 shows the status of the mapping *Ovary - ovary*, that was set with the value *correct*. In the alignment panel, users can also validate

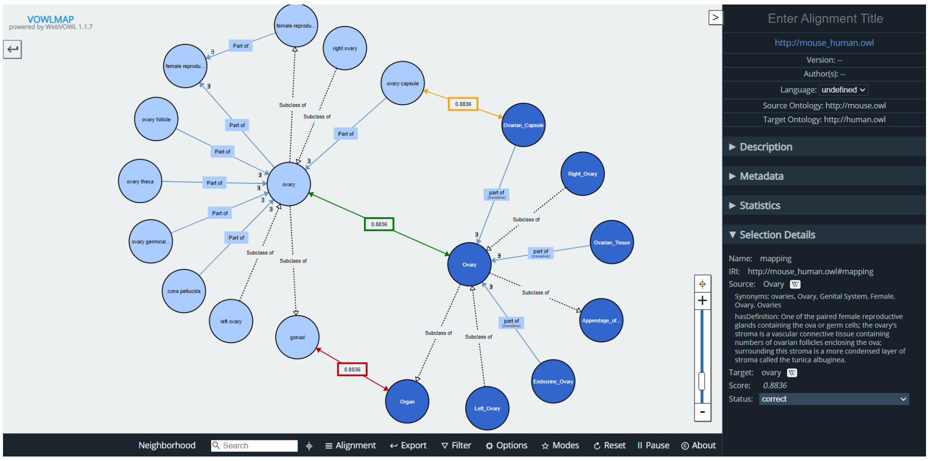

Fig. 2: VOWLMap visualization of a mapping.

a mapping in the sidebar, or in the status checkbox, by clicking on it. Each status has an associated color and icon to distinguish them.

The sidebar provides information about the source and target classes of a selected mapping, such as synonyms and definitions. For each mapped class, VOWLMap generates an automatic link to Wikipedia, which can help users obtaining more information. Figure 2 shows a clickable icon next to each class to open a Wikipedia page for that term in a new tab, if available. Furthermore, users can visualize an individual mapping and its local context, including neighboring mappings (Figure 2). By default, VOWLMap displays the neighborhood at a distance of 1, but users can change it from 0 to a maximum of 3 edges.

VOWLMap allows users to manually remove or add new mappings directly in the visualization. When a new mapping is created, the maximum score and the status *correct* are assigned to that mapping. In the alignment panel, users can create new mappings by entering the label of the respective source and target classes, and VOWLMap automatically generates a graph for that mapping. Moreover, users can refine an existing mapping by dragging the ends of its source or target nodes to a more suitable one.

The changes made to the alignment are saved in a cached version and, as long as VOWLMap is open in the browser, this version is always loaded, supporting interruptions in the validation process. A reload button allows users to discard these new changes and reload the original alignment. Moreover, VOWLMap allows exporting the validated alignment in several formats (e.g. RDF, JSON) or additionally, the complete or filtered rendering of a mapping in SVG.

Table 1 compares how VOWLMap and state-of-the-art ontology alignment systems comply with the requirements for alignment validation detailed in [7]. VOWLMap is the only tool that complies (totally or partially) with all requirements.

Table 1: Addressing of alignment validation requirements by VOWLMap and state-of-the-art ontology alignment systems.

	AM	AML	YAM++	COMA	VOWLMap
(R1) Load Alignments	✓	✓	✓	✓	✓
(R2) Alternative Views	×	✓	×	×	✓
(R3) Visual Info-Seeking Tasks	✓	✓✗	✓✗	✓✗	✓✗
(R4) Mapping Status	✓	✓	✓	×	✓
(R5) Metadata	✓	✓	×	×	✓
(R6) Context	✓✗	✓	×	×	✓
(R7) Accept/Reject mapping	✓	✓	✓	✓✗	✓
(R8) Create/Refine mapping	✓✗	✓✗	✓✗	✓	✓
(R9) Search	×	✓	✓	✓	✓
(R10) Session	✓✗	✓✗	✓✗	✓	✓
(R11) Export Alignments	✓	✓	✓	✓	✓

4 Evaluation

We performed a formative assessment study to guide the further development of VOWLMap. This study was observational and task-oriented, falling within the scope of the *creation* and *management* tasks of user studies in a Semantic Web context [11], given that the purpose of VOWLMap is to visualize, validate and edit ontology alignments.

4.1 Methodology

Four users were recruited from a pool of graduate students, with different backgrounds (life sciences, health sciences, computer science and engineering) and levels of expertise in alignment validation. All participants had prior knowledge of at least one of the domains of the aligned ontologies.

The evaluation focused on two small alignment validation tasks derived from the Conference and Anatomy tracks of OAEI 2020[2]. The first focused on an alignment between the ontologies *Conference* and *ekaw*, whereas the second focused on an alignment between the Adult Mouse Anatomy ontology and a part of the NCI Thesaurus describing human anatomy. Both alignments contained precisely 20 mappings, 10 of which were correct and selected from the reference alignment, with the other 10 being incorrect and selected from the erroneous mappings found by AML [3]. The selection of mappings was manual, and sought to ensure that there were both trivial (same label)

[2] http://oaei.ontologymatching.org/2020/

and non-trivial mappings among both correct and incorrect mappings, and that all incorrect mappings reflect some of the errors that automated tools make. The users were not aware of the proportion of positive and negative mappings in the tasks.

The study was performed remotely, with users employing VOWLMap on their machines. Participants were monitored and assisted by a researcher from our team via the *Zoom* platform, with participants sharing their screen but with cameras disabled. Audio and video were recorded with informed consent from the participants, collected through an online questionnaire[3]. This questionnaire also served to assess the profile of the user and collect details about the hardware, computer screen and web browser used by the participants, as well as to deliver the instructions of the tasks to the users and collect their feedback. The instructions required the users to watch a tutorial video[4], then download and run VOWLMap locally, validating the alignments provided for the study.

No instructions were given regarding the type or extent of validation required. Any questions regarding VOWLMap were answered. After each task, users uploaded the RDF file of their final alignment. Finally, users rated the features of VOWLMAP in a Likert scale, ranging from ”Not useful” to ”Very useful”. At the end of the questionnaire, an open-ended question allowed users to provide suggestions or feedback about VOWLMap.

4.2 Results and Discussion

To analyze the evaluation, we computed the duration of each task and each mapping validation action, the revision made by each user (i.e. count of mappings classified as correct, incorrect, and unsure, as well as new mappings added and existing mappings refined), the correctness of each validation action assessed with reference alignment (true and false positives and negatives, plus correct new and refined mappings), and the frequency of use of each VOWLMap feature. These results are compiled in Table 2 and the timeline of each validation task is depicted in Figure 3, presenting the time spent on each mapping and time spent in interruptions for requesting help or clarifications.

Four users were selected for this study, with different backgrounds (life sciences, health sciences, computer science and engineering, and bioinformatics) and levels of expertise in alignment validation. User 3 was the most experienced in ontology alignments, followed by User 4, whereas Users 1 and 2 had no previous experience. This is reflected in the outcomes of the validation, as Users 3 and 4 were quicker in the validation of both alignments, and User 3 was the only one to refine mappings, having 100% accuracy in mappings refined or added.

Table 3 displays the ratings given by each user to VOWLMap's several features, and Figure 4 depicts the frequency of use of each of those features per user and task.

All users had a fairly high accuracy classifying the mappings, ranging from 80% to 95% across the two tasks. The average accuracy was greater in Anatomy (91.3%) than Conference (86.3%) which mirrors the fact that automated alignment systems have worse results in the latter, suggesting it is a more difficult task. Users did take more

[3] https://bit.ly/36HreUP

[4] Available at: https://youtu.be/aCFtHtuN5Gk

Table 2: Evaluation statistics per task and user: mappings classified as Correct (Cor), Incorrect (Inc) or Unsure (Uns); New mappings added; mappings Refined (Ref); False Positives (FP), False Negatives (FN), True Positives (TP) and True Negatives (TN); New and Refined mappings that are Correct (New Cor and Ref Cor); and duration of the task (Time).

		Cor	**Inc**	**Uns**	**New**	**Ref**	**FP**	**FN**	**TP**	**TN**	**New Cor**	**Ref Cor**	**Time (mm:ss)**
Task 1 Conference	User 1	7	12	1	6	0	0	3	7	9	1	-	45:54
	User 2	11	9	0	1	0	1	0	10	9	1	-	30:50
	User 3	9	9	2	0	0	1	0	8	9	-	-	14:37
	User 4	9	10	1	0	0	1	1	8	9	-	-	10:32
Task 2 Anatomy	User 1	12	8	0	13	0	2	0	10	8	8	-	23:51
	User 2	11	9	0	2	0	1	0	10	9	2	-	43:53
	User 3	10	10	1	2	3	1	0	10	8	2	3	19:30
	User 4	9	9	2	0	0	0	0	9	9	-	-	08:35

Table 3: Rating of VOWLMap's features by each user.

	List Vis.	**List Valid.**	**List Editing**	**Graph Vis.**	**Graph Valid.**	**Graph Editing**	**Graph Interaction**	**Wikipedia Links**
User 1	5	5	5	5	5	5	5	4
User 2	4	4	5	5	5	5	5	4
User 3	5	4	5	5	5	5	5	4
User 4	5	5	4	5	4	3	5	4
Mean	4.73	4.72	4.73	5	4.73	4.40	5	4

time in average in Anatomy (122 minutes) than Conference (112 minutes), but this is likely due to a greater number of new and refined maps contributed (20 for Anatomy versus only 7 for Conference) which are time consuming. Interestingly, users identified erroneous mappings better in Conference than Anatomy, whereas the reverse was true for correct mappings.

User 2 was the only one not to classify any mapping as unsure, and also the one with the highest overall accuracy, with 95% in both tasks. Regarding the creation or refinement of mappings, User 1 was the most prolific but had an overall precision of only 47.4%. Users 2 and 3 created or refined only a few mappings, but with 100% precision, whereas User 4 neither created nor refined mappings. As users were asked to not remove the original mappings but rather mark them as incorrect, the use of the removing function is not reflected by Table 2. However, this feature was used by 3 users to remove mappings they previously added.

All users requested help or clarifications about VOWLMap, but time spent on this was comparatively short (2.5% - 9.8%).

Familiarity with VOWLMap seemingly had no bearing on the speed or accuracy with which users classified mappings, as initial mappings had neither higher time nor

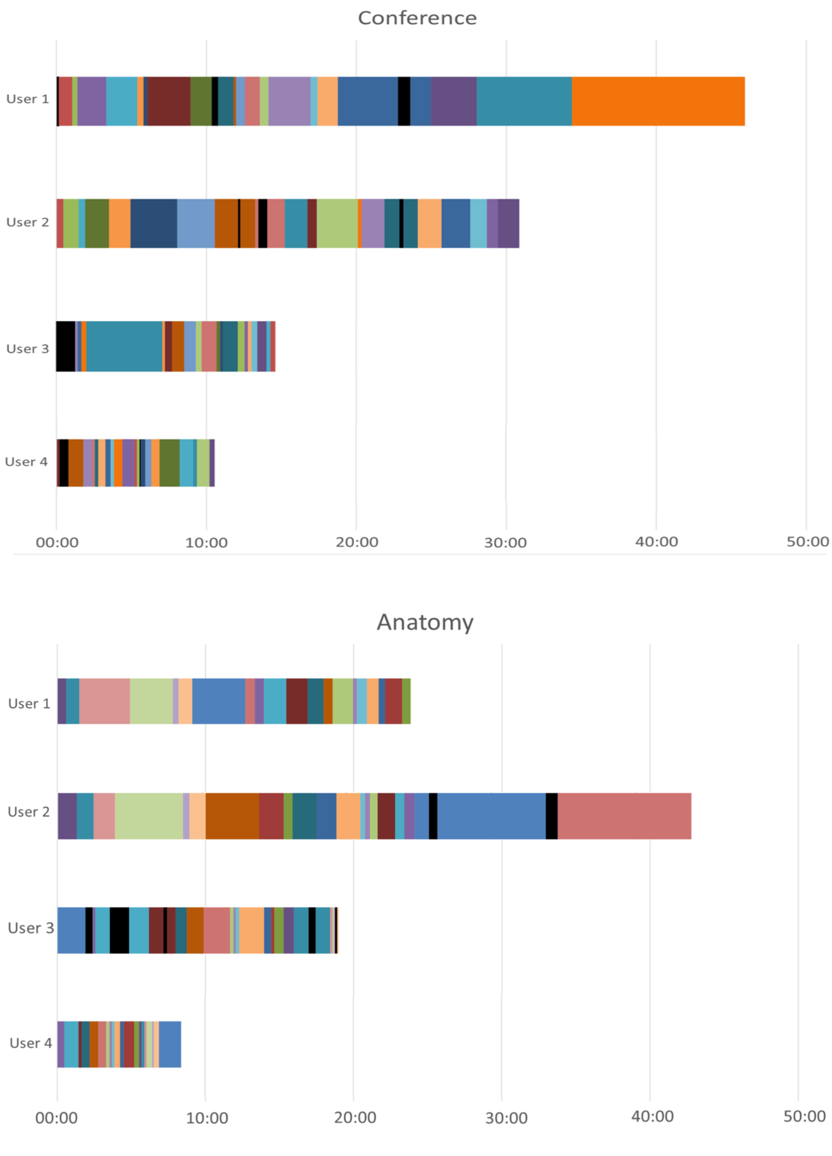

Fig. 3: Time spent validating Task 1 (Conference) and Task 2 (Anatomy), by each user. Each color represents a different mapping, with black representing interruptions for requesting help or clarifications about VOWLMap. The mapping corresponding to each color is at https://bit.ly/36HreUP

lower accuracy on average. On the contrary, Users 3 and 4 seem to have left mappings they found more challenging to classify for last, taking a lot more time in these. In-

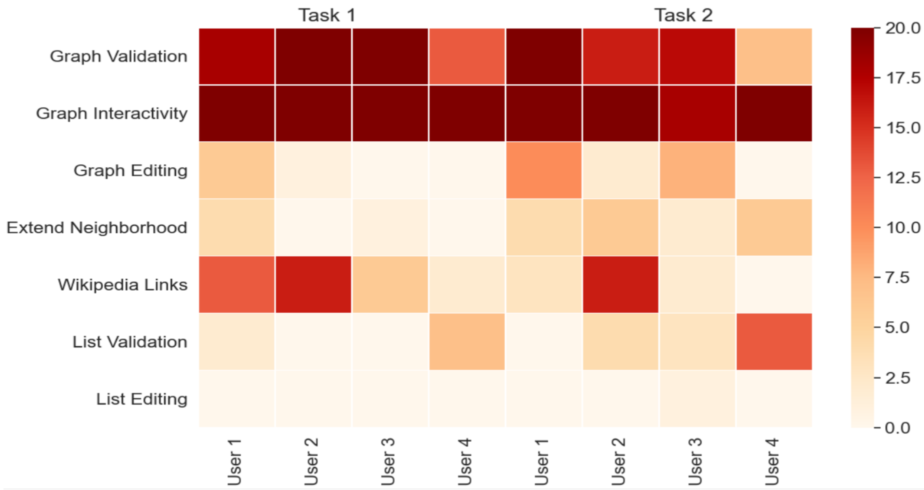

Fig. 4: Frequency of use of each VOWLMap feature, measured in number of mappings where the feature was used, for Task 1 (Conference) and Task 2 (Anatomy).

terruptions for help or clarification were also not concentrated at the start of the task, although Users 1 and 2 did ask for clarifications at the start of the evaluation. Overall, these facts speak well to the intuitiveness of VOWLMap's visualizations and functionalities.

With respect to VOWLMap's features, we note that *Wikipedia Links* received the lowest rating from users (4) likely because the links are automatically generated from the entities' labels, and sometimes there is no Wikipedia page available for a term. The only feature that was scored 3 by any user was *Graph Editing*, by user 4, who notably was the only user that attempted neither additions nor refinements of mappings, making the least use of this functionality among the four users. This functionality was more used in Anatomy than in Conference by the other three users, as they created and refined more mappings in the former than the latter. *Graph Visualization* and *Graph Interactivity* were consistently the highest rated features and the most used by users in both tasks.

5 Conclusions

We developed VOWLMap, a browser-based tool for ontology alignment visualization, validation and editing. VOWLMap provides both list and graph visualization of mappings, and supports the annotation of mappings as correct, incorrect and unsure, as well as the creation or refinement of mappings. VOWLMap complies with all the requirements for user validation of ontology alignments, laid out in [7] (albeit partially, in the case of the visual information seeking tasks), which sets it above established ontology alignment systems.

VOWLMap's evaluation in a small user study revealed that it is intuitive and easy to use, as no learning curve was observed with respect to the time or accuracy of the validation tasks. Moreover, users made use of most of VOWLMap's features, and generally considered them useful in the feedback they provided.

Future work could include adding features to provide overall statistics to assist in the validation process monitoring, such as displaying the mapping coverage for the aligned ontologies, the number of mappings reviewed by the current or previous user, and the number of changes made to that point. Additionally, it would be interesting to support validation of inter-annotator agreement, by allowing experts to exchange they intermediate results or by storing the revision along with the changes made by each author. Furthermore, we plan to integrate some of the qualitative assessments made by the users to further improve VOWLMap, as well as design a broader usability study, with in-person observations, to delve deeper into how users interact with the tool.

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