

27th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2023)

Phrase2Onto: A Tool to Support Ontology Extension

Mina Abd Nikooie Pour^a, Huanyu Li^a, Rickard Armiento^a, Patrick Lambrix^{a,b,*}

^aLinköping University and Swedish e-Science Research Centre, Sweden

^bUniversity of Gävle, Sweden

Abstract

Due to importance of data FAIRness (Findable, Accessible, Interoperable, Reusable), ontologies as a means to make data FAIR have attracted more and more attention in different communities and are being used in semantically-enabled applications. However, to obtain good results while using ontologies in these applications, high quality ontologies are needed of which completeness is one of the important aspects. An ontology lacking information can lead to missing results. In this paper we present a tool, *Phrase2Onto*, that supports users in extending ontologies to make the ontologies more complete. It is particularly suited for ontology extension using a phrase-based topic model approach, but the tool can support any extension approach where a user needs to make decisions regarding the appropriateness of using phrases to define new concepts. We describe the functionality of the tool and a user study using Pizza Ontology. The user study showed a good usability of the system and high task completion. Further, we report on a real application where we extend the Materials Design Ontology.

© 2023 The Authors. Published by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

Peer-review under responsibility of the scientific committee of the KES International.

Keywords: Ontology extension; Concept discovery; phrase-based topic model.

1. Introduction

An ontology represents a domain of interest [23]. Ontologies have been used to annotate data of a domain to make the data FAIR (Findable, Accessible, Interoperable and Reusable) [24]. In terms of using ontologies in semantically-enabled applications, high-quality ontologies are needed to produce good results. One of the aspects of quality in ontologies is completeness. An ontology lacking information may lead to missing inferences and thus incomplete results which may, e.g., make data not accessible.

One way to make ontologies more complete, is ontology extension. Editors such as Protégé¹ and the Ontology Development Kit (ODK) [18], can be used for this task when the information to be added is already known. On-

* Corresponding author.

E-mail address: patrick.lambrix@liu.se

¹ <https://protege.stanford.edu/>

toPlus [19] is a text mining-based ontology extension method using ontology content, structure and co-occurrence information in the ontology. The user specifies the input ontology and domain keywords, and then a list of candidate concepts related to other glossaries will be displayed. Ontology learning approaches can also be used for ontology extension. For instance, Text2Onto [6] is a framework to learn ontologies from textual documents. It extracts terms (concepts) and relations between them from text and provides a user interface in which different configuration views can be selected by the user (e.g., concept, instance, similarity). RepOSE [11, 17] is a system that proposes new axioms between existing concepts to be added to an ontology and provides a user interface to make the validation of these axioms easy for the domain expert. Further, machine learning-based approaches are used for ontology learning. In [8], a machine learning-based method is proposed to find the most relevant ontologies to a given text. In [3], deep learning-based models are used to extract semantic relations from scientific text. In [22], a deep learning based method is used for relation extraction in the biomedical domain. Also, there are methods to extract relations for ontologies. For example, RelExt [21] is a tool for extracting relations from text using linguistic and statistical methods.

Another kind of ontology extension technique is based on phrase-based topic model approaches. In such approaches, frequent phrases are collected from unstructured text, and phrases that are connected to each other, are collected in a set and presented as a topic. These phrases and topics can be used for formulating concepts and extending the concept hierarchy. In our previous work [15] we used such a topic model-based method to extend ontologies in the materials science field. One of the lessons learned was that tool support was needed for these kinds of approaches. However, to our knowledge no such tools exist.

The contribution of this paper is a tool, *Phrase2Onto*, for phrase-based ontology extension. The tool takes as input a list of phrases and lists of topics, which can be generated by methods as in [15] or by any other methods, and supports the user in extending the ontology. We also evaluate the usability of the tool using a user study and the feasibility of using the tool in a real-world application.

The paper is organized as follows. In Section 2 we present basics in ontologies and describe a phrase-based topic model approach for ontology extension. Further, we present the two ontologies that we used in this study: *Pizza Ontology* and *Materials Design Ontology*. In Section 3 we describe the *Phrase2Onto* tool. The tool including the source code, the files for the demonstration as well as a demonstration video are available at <https://github.com/LiUSemWeb/phrase2onto>. The user study using *Pizza Ontology* and its results are presented in Section 4. In Section 5 we show a real-world application where we extend the *Materials Design Ontology*. Finally, the paper concludes in Section 6.

2. Background

2.1. Ontologies

From a knowledge representation point of view, ontologies may contain four components: (i) concepts that represent sets or classes of entities in a domain (e.g., *Pizza*, *Food*), (ii) instances that represent the actual entities (not discussed in this paper), (iii) relations (e.g., *hasTopping* represents the relation between a pizza and its topping), and (iv) axioms that represent facts that are always true in the domain of the ontology. Axioms can represent such things as domain restrictions, cardinality restrictions, or disjointness restrictions. For instance, the axiom *Pizza is-a Food* states that all pizzas are food. A common way to represent ontologies is using OWL (Web Ontology Language) which is a W3C standard².

The two ontologies that we extend with *Phrase2Onto* in this paper are the *Pizza Ontology* and the *Materials Design Ontology*. *Pizza Ontology*³ was developed at the University of Manchester as an example ontology for educational purposes⁴. The ontology models pizzas and their toppings. There are 100 concepts, 8 relations and 801 axioms in the ontology. It contains, for instance, the concepts *Pizza*, *PizzaBase* and *PizzaTopping* that are sub-concepts of the concept *Food*.

² <https://www.w3.org/OWL/>

³ <https://protege.stanford.edu/ontologies/pizza/pizza.owl>

⁴ A Quick Demonstration: <https://protegewiki.stanford.edu/wiki/Protege4Pizzas10Minutes>

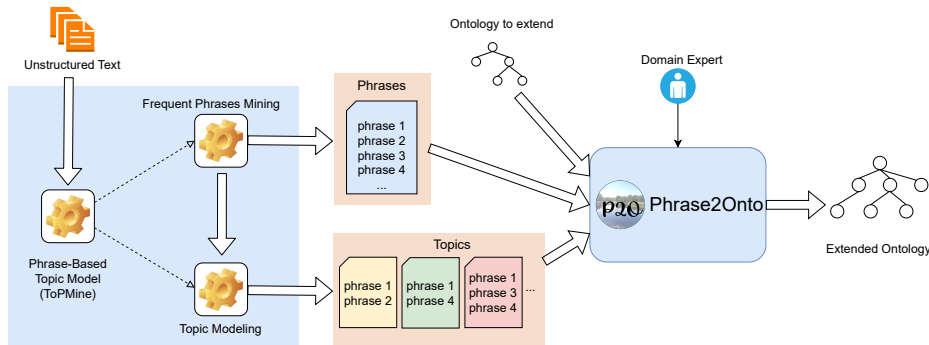


Fig. 1: Approach presented in [15] and its relationship with *Phrase2Onto*: The figure shows the creation of a phrase-based topic model with unstructured text as input and phrases and topics as output. Then a domain expert validates and interprets the results. *Phrase2Onto* supports the validation effort of the domain expert.

The *Materials Design Ontology*⁵ (MDO) [16, 10] models basic concepts for materials design with the purpose of supporting semantic search and integration of materials databases. It has four modules: *Core*, *Structure*, *Calculation* and *Provenance*. These modules represent concepts related to basics for materials design, structure of materials, materials calculations and provenance. MDO consists of 37 concepts, 32 relations and 113 axioms.

2.2. Phrase-based Topic Model Approach for Ontology Extension

We used the phrase-based topic model generation approach we presented in [15] in our real-world scenario (Figure 1). Using a corpus of documents related to the domain of interest, first, frequent contiguous phrases are mined, which consists of collecting aggregate counts for all contiguous words satisfying a user-defined minimum support threshold. After the phrase mining, topic modeling is performed by computing representations of latent topics in the documents. Topics are generated using a variant of Latent Dirichlet Allocation (LDA) [4], called *PhraseLDA*, that deals with phrases, rather than words. Essentially, topics can be seen as a probability distribution over words or phrases. The system that is used in [15] for generating the frequent phrases and topics is *ToPMine* [7]. A variant of *ToPMine* where a user-defined maximum threshold is used to remove common words that are likely not interesting for the ontology, and that we use in this paper, is presented in [1].

The frequent phrases as well as the topics (and possibly sub-topics) can be used for defining new concepts in the ontology and thereby extend the ontology. To obtain high-quality extensions, this requires, however, intellectual effort and validation work by a domain expert. From previous experiences (e.g., [2]) it is clear that tool support is needed. The tool proposed in this paper provides support for this kind of validation work.

3. *Phrase2Onto*: A Tool for Ontology Extension

Phrase2Onto is a tool to support users in the user validation phase⁶ of ontology extension approaches that use phrases and/or topics to define new concepts and new connections between them as axioms. The tool contains five tabs representing the different steps in the ontology extension workflow: **Set-up**, **Phrases→Concepts**, **Topics→Concepts**, **Concepts** and **Concepts→Axioms**. We note that the ontology extension workflow is flexible and, except for the Set-up which is always the first step, there is no required order in which the user needs to use different tabs. The user can use different orders as well as interleave steps. In this section we present details of each tab in the tool and use *Pizza Ontology* to exemplify the steps. Similar to most ontology engineering systems, better results are obtained when the

⁵ <http://w3id.org/mdo/full/1.0/>

⁶ In this paper, validation refers to the domain expert deciding whether a phrase or topic can be used to define new concepts and axioms for the ontology. Note that this is not validation of the final ontology in the sense of, e.g., consistency checking. The final ontology could be validated and repaired by debugging systems [9].

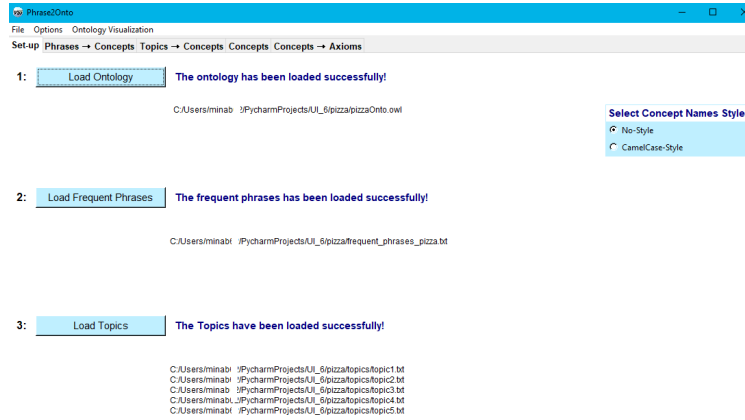


Fig. 2: Set-up tab of *Phrase2Onto*.

user or team of users of the tool are expert in ontology engineering as well as in the domain of the ontology that needs to be extended.

3.1. Set-up tab

Set-up is used for loading the input files. With *Load Ontology* the ontology to be extended is loaded in OWL format. A text file with the list of phrases is loaded using *Load Frequent Phrases*. Further, text files containing the topics are loaded using *Load Topics*. In Figure 2, we load *Pizza Ontology* as well as phrases and topics.

3.2. Phrases→Concepts tab

In this tab new concepts based on the phrases can be defined. In Figure 3a, we select *Margherita* from *Phrases list*. For each selected phrase, there are three sub-tabs. In the *Define concept from selected phrase* sub-tab, a new concept based on the selected phrase can be defined with as name the selected phrase or a variant of it (*Use the phrase itself* and *Define new form of the phrase* in Figure 3a). Newly defined concepts are added to the *Concepts list* and are displayed in a different color than the concepts in the original ontology (Figure 5). We can add multiple concepts related to a phrase. Information about newly defined concepts from the selected phrase is displayed under *Extracted Concepts from Phrase*.

If there exist concepts in the original ontology that are related to the selected phrase, we can connect these concepts to the phrase by using *Relate Concepts to Phrase*. For example, in Figure 3a, we connect the *MargheritaPizza* concept to the selected phrase *Margherita*. This information is displayed under *Related Concepts to Phrase* (Figure 3a).

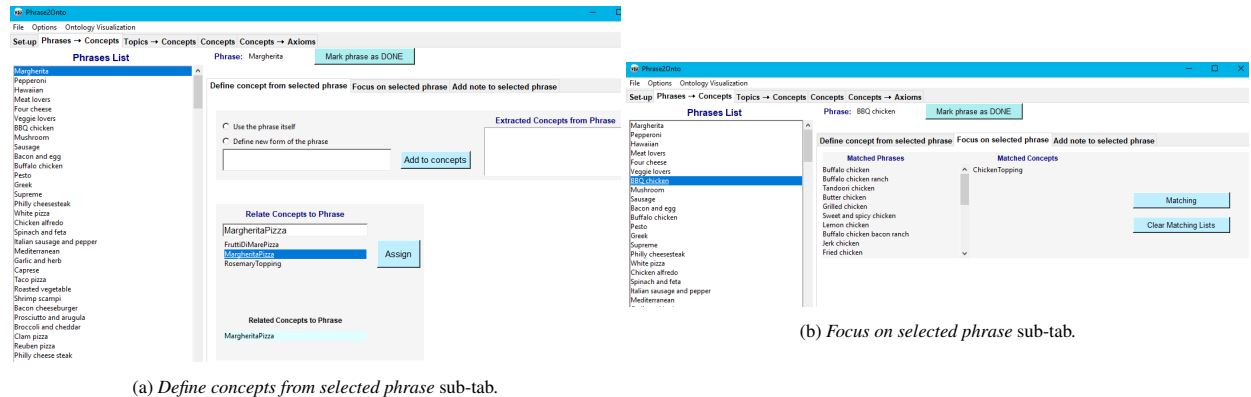


Fig. 3: *Phrases→Concepts* tab of *Phrase2Onto*.

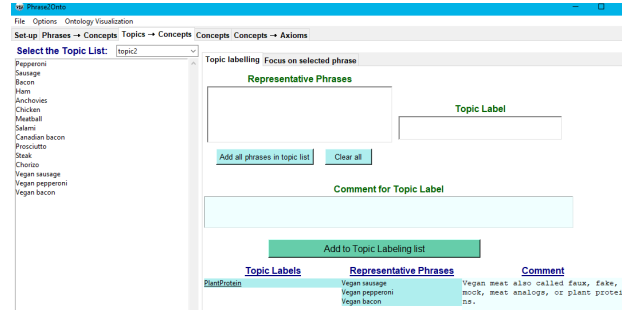


Fig. 4: Topics→Concepts tab of Phrase2Onto.

In the *Focus on selected phrase* sub-tab, phrases and concepts similar to the selected phrase can be retrieved from the phrases list and ontology, respectively (Figure 3b). For example, in Figure 3b, we have matched phrases and concepts of BBQ chicken phrase. Phrases and concept names are defined as matching if they have at least one word with the same stem in common. This allows for insights regarding relationships among the original as well as added concepts. The last sub-tab is *Add note to the selected phrase* in which notes can be added to the selected phrase.

3.3. Topics→Concepts tab

In this tab new concepts can be defined that are related to topics or sub-topics. As mentioned earlier, topics are represented by lists of phrases that often occur together. A sub-topic is represented by a subset of the list of phrases of the topic. In this tab, a topic from the topics list is selected and its representing phrases are displayed. In Figure 4, we have selected *topic2*. To create a new concept the user selects some (sub-topic) or all (topic) phrases in the displayed list (using the *add all phrases in topic list* button), defines a label for this list of phrases (*Topic Label*) and adds a new concept to the ontology with as name this topic label (Figure 4). For instance, in Figure 4, we selected the phrases Vegan bacon, Vegan sausages and Vegan pepperoni in *topic2* and labeled this sub-topic of *topic2* as PlantProtein. A comment is added as well. The topic label is added to *Topic Labels* after pressing the *Add to Topic Labeling List* button. Further, a concept can be created from the topic label by the available pop-up menu *Create concept from topic label* and *Edit*. Multiple topic labels can be defined for a topic. In the *Focus on selected phrase* sub-tab, there is information regarding the possibly multiple topics that include the phrase and topic labels related to the phrase.

3.4. Concepts tab

The focus of this tab is on concepts. For each selected concept from *Concepts list*, there are two sub-tabs. In the *Define new concept* sub-tab (Figure 5a), new concepts can be defined that are not necessarily related to a phrase or topic label. This was a request by domain experts in previous experiments (described in [1]) where they, during and inspired by the validation process, sometimes wanted to add relevant new concepts that were not directly connected to phrases and topics. In the example in Figure 5a we add a new concept GlutenFreePizza and write a comment. Further, for the concepts in the ontology, information such as its origin (e.g., the original ontology or a phrase) is in the *Info on selected concept* sub-tab.

3.5. Concepts→Axioms tab

In this tab new axioms can be defined by the user (Figure 5b). For a selected concept from the *Concepts list*, in the *Define axioms for the selected concept* sub-tab, the user can define new subsumption axioms representing that the selected concept is a sub-concept or super-concept of another concept by using the first or second radio button, respectively. For instance, in Figure 5b we add NamedPizza as a super-concept of HawaiianPizza, thereby defining the axiom HawaiianPizza is-a NamedPizza. Further, information on all axioms in which the selected concept as well as its super-concepts and sub-concepts, are involved, is displayed. For instance, in the example in Figure 5b we

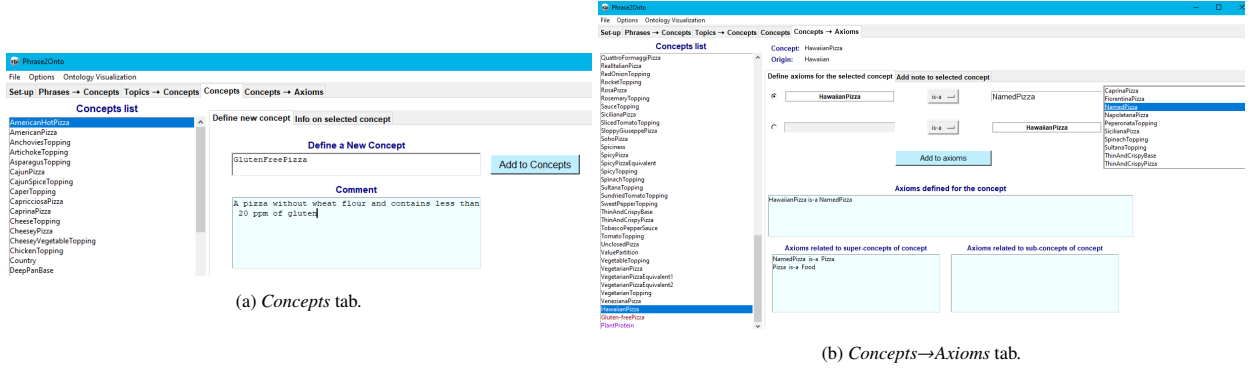


Fig. 5: *Concepts* and *Concepts→Axioms* tabs in *Phrase2Onto*.

see that *Pizza* and *Food* are now super-concepts of *HawaiianPizza*. This information is updated when a new axiom is added. Moreover, a note can be written and edited in the *Add note to the selected concept* sub-tab.

3.6. Additional Functionalities

In the tabs introduced above, during the validation users can mark phrases and concepts in different ways as a support to remember which items have been dealt with. In the *Phrase2Onto* menu bar, the **File** menu contains functionalities related to creating, opening and saving files including saving partial results that can be loaded again at a later time. The **Options** menu contains functionality related to searching phrases, concepts and axioms and displaying information related to axioms or topic labeling and export the information as a text file. Moreover, **Ontology Visualization** allows to visualize the ontology as well as the changes made. The new concepts and axioms are displayed in a different color than the concepts and axioms in the original ontology to make it easier to differentiate the added ones from to the original ones.

4. A User Study based on Extending the Pizza Ontology

To evaluate the functionality and usability of our tool, we performed a user study where the participants completed different tasks to extend the *Pizza Ontology*. For generating frequent phrases and topics regarding *Pizza Ontology*, we used ChatGPT⁷ and had a question answering session about pizzas and their toppings. We asked questions such as provide a list of 200 different pizzas with their ingredients, and list the names of different toppings for pizza. The whole session is available online⁸.

We follow the guidelines on how to report on user studies in the Semantic Web context from [20]. This includes descriptions of the users, the user study tasks, the setup and procedure of the study, and the analysis and presentation of the data. In total, 12 individuals participated in the study, 10 PhD students and 2 Postdocs in computer science. As the *Pizza Ontology* is easy to understand, they know about the field but they are not expert in the food industry. In total, 5 out of the 12 participants are familiar with Semantic Web (shown in light green color in Table 1).

In preparation for the study, we provided a tutorial document of the tool to the participants and asked them to read the document before the actual study. During the session, we asked the participants to perform 12 step-by-step tasks. The tasks included such things as setting up the workspace, defining new concepts based on phrases, topic labeling and defining concepts from topic labels. The tutorial document and tasks file is available online⁹. Then, we asked the participants to answer two questionnaires. Each session took around 1 hour in total for completing the tasks and answering the questionnaires.

⁷ <https://chat.openai.com>

⁸ <https://shareg.pt/uc7artm>

⁹ https://github.com/LiUSemWeb/phrase2onto/blob/main/KES2023_Phrase2Onto/UserStudy_Tutorial_Phrase2Onto.pdf

Table 1: Results of the user study questionnaires SUS and PSSUQ)

(a) SUS scores (Best score=100).

Participant	SUS Score
P1	70
P2	87.5
P3	50
P4	67.5
P5	65
P6	80
P7	70
P8	85
P9	62.5
P10	82.5
P11	67.5
P12	82.5
Average	72.5

(b) PSSUQ scores (Best score=1).

Participant	Overall	SYSUSE	INFOQUAL	INTERQUAL
P1	2.56	2.5	2.67	2.6
P2	1.27	1.5	1.2	1
P3	3.31	2.67	3.67	4
P4	2.13	1.5	2.67	2.5
P5	4.19	4	3.83	5.33
P6	2.4	2	3.17	1.5
P7	2.21	1.67	2.5	3.33
P8	2.25	2.33	2.17	2.33
P9	3.75	4.5	2.5	4.67
P10	2.071	2.17	2	2
P11	2.8	2.67	2.6	3.67
P12	1	1	1	1
Average	2.495	2.376	2.498	2.828

To evaluate the usability of the tool, we used two types of standard questionnaires: *System Usability Scale (SUS)* [5] and *Post-Study System Usability Questionnaire (PSSUQ)*¹⁰ [12]. SUS is a quick way to assess the system usability [5]. The SUS questionnaire consists of 10 questions with five response options from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*). In the SUS questionnaire, the center point of the scale 3 should be selected if the participant cannot answer the question. Based on the answers, a SUS score is calculated according to the calculation method in [5]. A SUS score is in the range 0-100, but should not be interpreted as percentages. A SUS score above 68 is considered as above average and otherwise, it is below average¹¹. Higher scores mean higher user satisfaction. PSSUQ is a 16-questions questionnaire with eight options, from 1 (*Strongly Agree*) to 7 (*Strongly Disagree*) and the *N/A* option. PSSUQ leads to an *Overall score* and three sub-scores *SUSUSE*, *INFOQUAL* and *INTERQUAL* which stand for *System Usefulness*, *Information Quality* and *Interface Quality*, respectively. Lower scores mean better performance and higher satisfaction. In Table 1, the *Average* score is the sum of the scores in the same column divided by 12 (the number of participants). In addition to the usability scores, we also used task completion as an evaluation metric. During the session while using the system, the participants were asked to think loud and notes were taken. Further, after they filled out the questionnaires there was a small discussion with the observer about their thoughts regarding the tool, and the kind of functionality they expected from such a tool and what kind of functionality they lacked.

4.1. Results and Interpreting Scores

The results of the user study questionnaires are presented in Table 1. The average SUS score of our user study is **72.5** (Table 1a). As the average SUS score is higher than **68**, the evaluation of *Phrase2Onto* is above average according to [13]. Moreover, the average SUS score for the participants who are familiar with the Semantic Web field (P2, P4, P7, P8 and P11, shown in light green in Table 1a) is **75.5** which is higher than the average SUS score for all participants (**72.5**).

The average scores of the study for PSSUQ questionnaire are **2.495**, **2.376**, **2.498** and **2.828** for Overall, SYSUSE, INFOQUAL and INTERQUAL, respectively. The average scores for the participants who are familiar with the Semantic Web field (shown in light green in Table 1b) are **2.132**, **1.934**, **2.228**, and **2.566**, respectively which are a bit lower and thus better results compared to the scores for all participants. We note that the scores for P12 seem too good (especially as the learning curve for P12 was higher than for 9 other participants), but we add these for completeness. However, the conclusions regarding the usability of the system still hold when we ignore P12.

¹⁰ <https://uiuxtrend.com/pssuq-post-study-system-usability-questionnaire/>

¹¹ <https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html>

The task completion rate was high. Out of 12 participants, 8 participants finished all the tasks, 2 participants (P6 and P12) missed one sub-task (adding a new concept and then delete it) and 2 other participants (P3 and P5) missed the same sub-task as well as another one (defining a topic label, adding it to topic labelling info, and then edit it). The reason for these missed sub-tasks is that the participants read ahead in the task description and created a result for the combined sub-tasks.

Through the thinking loud during the use of the tool and their task performance, we observed that 9 participants became familiar with the tool and the workflow after the second or third task. For example, the participants managed to get back to the right path themselves if they chose the wrong tab to complete a task. For 3 participants (P3, P6, and P12) it took longer to learn the workflow and the tool until after the fifth or sixth task. Some participants made mistakes while performing tasks such as searching. For instance, when asked to search for a phrase in the phrase list, they opened the concept list and tried to find the phrase there, or did not select the correct option in *find window* to search within phrases list.

Sometimes participants had difficulties to differentiate between the tabs due to the color of the header. Although the color of the current tab's header is white and the color of the other headers grey, this was not always very visible on all screens.

4.2. Lessons Learned

In general, to obtain the best results, ontology engineering tools require (teams of) users to be familiar with ontologies and with the domain of the ontology for extension. Therefore, it was important that, in the user study, we used an ontology for which the domain was easy to understand. The results show that our choice of *Pizza Ontology* was a good choice as all participants felt that they understood the domain.

Familiarity with the Semantic Web or ontologies influenced the results. In addition to having that perspective, the participants that were familiar with the Semantic Web did not question the need for a tool like *Phrase2Onto*. The other participants did question this even though the motivation for developing *Phrase2Onto* was explained in the tutorial document. The usability scores for the participants familiar with the Semantic Web were better than for the other participants.

Another aspect of lessons learned is regarding the design of the user interface. The appearance of the tool such as the colors of the tabs and their headers and the color of the buttons, should be defined in a way to help the user notify them simply. For instance, in the user study some participants had difficulties to distinguish between the different headers of the tabs. As a result, they required more time to finish a task. However in general, the participants mentioned that the components in the different tabs have straightforward meanings. Moreover, the displayed messages in the tool were helpful. In some cases participants would have liked additional information. For instance, in the *Focus on selected phrase* sub-tab of the *Phrases*→*Concepts* tab, if there are no matched concepts or phrases for the selected phrase, the participants would like a message that there are no matched concepts or phrases to be displayed.

The expectations of the participants in the user study regarding how some user interactions should be performed, influence the results. For instance, some participants expected that, while selecting a set of phrases for a sub-topic, that these could be dragged and dropped in the *Representative Phrases* panel. As this was not the case, this was considered a negative aspect of the user interface even though the required functionality was available. Further, some additional *help* features in the menu bar or appropriate pop-up messages to guide the user through the tool, were requested. The existing messages from the tool (e.g., confirmation after adding concepts) were considered useful.

5. An Application on Extending the Materials Design Ontology

In this section we describe how we used *Phrase2Onto* in a real-world application to extend MDO. Since MDO has been used for data integration purposes in the materials science field [14], extending MDO would allow for a larger coverage of databases to integrate. We used the method presented in Section 2.2 to generate phrases and topics related to MDO. To obtain relevant unstructured text, we used MDO's concepts to query two journals (i.e., NPJ Computational

Materials¹² and Computational Materials Science¹³). We retrieved the titles and abstracts of the returned papers and used them as input to a new version of ToPMine described in [1], to generate the frequent phrases and topics. In total, we obtained 131 phrases and 10 topics. We had a 2 hours session with a domain expert to extend MDO using *Phrase2Onto*. Based on the phrases, using the Phrases→Concepts tab the domain expert defined 29 new concepts (e.g., *StackingFault* and *FaceCenteredCubic*) and 27 new axioms (e.g., *StackingFault is-a DefectType*). Then, the domain expert labeled topics in the Topics→Concepts tab and divided topics into sub-topics. In total, 10 new concepts were added to the ontology using topic labels and 10 new axioms (one for each new concept). For instance, the domain expert defined a new concept *MaterialsProperty* as a sub-concept of *PhysicalProperty* (an existing concept in MDO) as well as 8 new concepts (from topic labels) as sub-concepts of the *MaterialsProperty* concept. Moreover, a new concept *ElectronicStructureFeature* was defined as a sub-concept of *Property*. The results of the MDO extension project are available online as a pkl file¹⁴ that can be loaded as an existing project into *Phrase2Onto*, as well as a text file¹⁵ containing the newly added concepts and axioms.

The domain expert found the workflow clear. The fact that not only phrases could be used as a basis to define new concepts, but also topics, was considered positive as the topics represented information about the connections between different concepts. The domain expert commented on some user interface issues. A first such issue was a recommendation to unify the creation of concepts as much as possible, whether the concept is generated from phrases or from topics. Further, as the order in the workflow is flexible, a back button allowing the user to go back to the previously used tab would be considered beneficial.

6. Concluding Remarks and Future Work

In this paper we presented a tool, *Phrase2Onto*, that supports users in extending ontologies. It is particularly suited for ontology extension using a phrase-based topic model approach, but the tool can support any extension approach where a user needs to make decisions regarding the appropriateness of using phrases to define new concepts.

To evaluate the functionality and usability of *Phrase2Onto*, we conducted a user study where 12 participants extended the well-known educational ontology *Pizza Ontology*. In general, the result of the user study shows that our tool contains reasonable functionality and led to high task completion. The tool received over average scores for two well-known methods for evaluating usability.

We also applied our tool in a real-world application scenario where a domain expert used the tool to extend the *Materials Design Ontology*. This real-world application shows that our tool supports a domain expert in the validation work related to ontology extension.

For the future, we will use *Phrase2Onto* in the EU Onto-DESIDE¹⁶ project, where currently new ontologies regarding circular economy are being developed.

In terms of the implementation of the tool, we will implement new functionality based on the feedback obtained from the user study, such as adding *help* to the main menu, converting notes of users' validation on concepts to annotations for the extended ontology, and changing the colors for tracing the tabs.

Acknowledgements

This work has been financially supported by the Swedish e-Science Research Centre (SeRC), the Swedish National Graduate School in Computer Science (CUGS), and the Swedish Research Council (Vetenskapsrådet, dnr 2018-04147). We thank the participants in the user study.

¹² <https://www.sciencedirect.com/journal/computational-materials-science>

¹³ <https://www.nature.com/npjcompumats/>

¹⁴ https://github.com/LiUSEmWeb/phrase2onto/blob/main/KES2023_Phrase2Onto/MDO_extension_v1.pkl

¹⁵ https://github.com/LiUSEmWeb/phrase2onto/blob/main/KES2023_Phrase2Onto/new_conceptc_MDO_v1.txt

¹⁶ <https://ontodeside.eu/>

References

- [1] Abd Nikooie Pour, M., Li, H., Armiento, R., Lambrix, P., 2021a. A First Step towards a Tool for Extending Ontologies, in: Proceedings of the Sixth International Workshop on the Visualization and Interaction for Ontologies and Linked Data co-located with the 20th International Semantic Web Conference (ISWC 2021), CEUR-WS.org. pp. 1–12. URL: <http://ceur-ws.org/Vol-3023/paper2.pdf>.
- [2] Abd Nikooie Pour, M., Li, H., Armiento, R., Lambrix, P., 2021b. A First Step towards Extending the Materials Design Ontology, in: Workshop on Domain Ontologies for Research Data Management in Industry Commons of Materials and Manufacturing - DORIC-MM, pp. 1–11.
- [3] Al-Aswadi, F.N., Chan, H.Y., Gan, K.H., 2021. Extracting Semantic Concepts and Relations from Scientific Publications by Using Deep Learning, in: Innovative Systems for Intelligent Health Informatics: Data Science, Health Informatics, Intelligent Systems, Smart Computing. Springer, pp. 374–383. doi:[10.1007/978-3-030-70713-2_35](https://doi.org/10.1007/978-3-030-70713-2_35).
- [4] Blei, D.M., Ng, A.Y., Jordan, M.I., 2003. Latent Dirichlet Allocation. *Journal of Machine Learning Research* 3, 993–1022.
- [5] Brooke, J., 1996. SUS-A quick and dirty usability scale, in: Usability evaluation in industry, pp. 189–194. URL: <https://www.taylorfrancis.com/chapters/edit/10.1201/9781498710411-35/sus-quick-dirty-usability-scale-john-brooke>.
- [6] Cimiano, P., Völker, J., 2005. Text2Onto - A Framework for Ontology Learning and Data-driven Change Discovery, in: Proceedings of the 10th international conference on applications of natural language to information systems (NLDB), pp. 227–238. doi:[10.1007/11428817_21](https://doi.org/10.1007/11428817_21).
- [7] El-Kishky, A., Song, Y., Wang, C., Voss, C.R., Han, J., 2014. Scalable Topical Phrase Mining from Text Corpora. *Proceedings of the VLDB Endowment* 8, 305–316. doi:[10.14778/2735508.2735519](https://doi.org/10.14778/2735508.2735519).
- [8] Korel, L., Yorsh, U., Behr, A.S., Kockmann, N., Holeña, M., 2023. Text-to-Ontology Mapping via Natural Language Processing with Application to Search for Relevant Ontologies in Catalysis. *Computers* 12, 14. doi:[10.3390/computers12010014](https://doi.org/10.3390/computers12010014).
- [9] Lambrix, P., 2023. Completing and debugging ontologies: State of the art and challenges in repairing ontologies. *ACM Journal of Data and Information Quality* doi:[10.1145/3597304](https://doi.org/10.1145/3597304).
- [10] Lambrix, P., Armiento, R., Li, H., Hartig, O., Abd Nikooie Pour, M., Li, Y., 2023. The Materials Design Ontology. *Semantic Web Journal*.
- [11] Lambrix, P., Ivanova, V., 2013. A unified approach for debugging is-a structure and mappings in networked taxonomies. *Journal of Biomedical Semantics* 4, 10. doi:[10.1186/2041-1480-4-10](https://doi.org/10.1186/2041-1480-4-10).
- [12] Lewis, J.R., 1992. Psychometric Evaluation of the Post-Study System Usability Questionnaire: The PSSUQ, in: Proceedings of the human factors society annual meeting, Sage Publications Sage CA: Los Angeles, CA. pp. 1259–1260. doi:[10.1177/154193129203601617](https://doi.org/10.1177/154193129203601617).
- [13] Lewis, J.R., Sauro, J., 2018. Item Benchmarks for the System Usability Scale. *Journal of Usability Studies* 13, 158–167. URL: <https://uxpajournal.org/item-benchmarks-system-usability-scale-sus/>.
- [14] Li, H., 2022. Ontology-Driven Data Access and Data Integration with an Application in the Materials Design Domain. Ph.D. thesis. Linköping University, Sweden. doi:[10.3384/9789179292683](https://doi.org/10.3384/9789179292683).
- [15] Li, H., Armiento, R., Lambrix, P., 2019. A Method for Extending Ontologies with Application to the Materials Science Domain. *Data Science Journal* 18. doi:[10.5334/dsj-2019-050](https://doi.org/10.5334/dsj-2019-050).
- [16] Li, H., Armiento, R., Lambrix, P., 2020. An Ontology for the Materials Design Domain, in: The Semantic Web - ISWC 2020 - 19th International Semantic Web Conference, Proceedings, Part II, Springer. pp. 212–227. doi:[10.1007/978-3-030-62466-8_14](https://doi.org/10.1007/978-3-030-62466-8_14).
- [17] Li, Y., Lambrix, P., 2023. Repairing \mathcal{EL} ontologies using weakening and completing, in: The Semantic Web - 20th International Conference, ESWC 2023, Springer. pp. 298–315. doi:[10.1007/978-3-031-33455-9_18](https://doi.org/10.1007/978-3-031-33455-9_18).
- [18] Matentzoglou, N., Goutte-Gattat, D., Tan, S.Z.K., Balhoff, J.P., Carbon, S., Caron, A.R., Duncan, W.D., Flack, J.E., Haendel, M., Harris, N.L., Hogan, W.R., Hoyt, C.T., Jackson, R.C., Kim, H., Kir, H., Larralde, M., McMurry, J.A., Overton, J.A., Peters, B., Pilgrim, C., Stefancsik, R., Robb, S.M., Toro, S., Vasilevsky, N.A., Walls, R., Mungall, C.J., Osumi-Sutherland, D., 2022. Ontology Development Kit: a toolkit for building, maintaining and standardizing biomedical ontologies. *Database* 2022. doi:[10.1093/database/baac087](https://doi.org/10.1093/database/baac087).
- [19] Novalija, I., Mladenčić, D., Bradeško, L., 2011. Ontoplus: Text-driven ontology extension using ontology content, structure and co-occurrence information. *Knowledge-Based Systems* 24, 1261–1276. doi:[10.1016/j.knosys.2011.06.002](https://doi.org/10.1016/j.knosys.2011.06.002).
- [20] Pesquita, C., Ivanova, V., Lohmann, S., Lambrix, P., 2018. A Framework to Conduct and Report on Empirical User Studies in Semantic Web Contexts, in: Knowledge Engineering and Knowledge Management - 21st International Conference, EKAW 2018, Proceedings, Springer. pp. 567–583. doi:[10.1007/978-3-030-03667-6_36](https://doi.org/10.1007/978-3-030-03667-6_36).
- [21] Schutz, A., Buitelaar, P., 2005. RelExt: A Tool for Relation Extraction from Text in Ontology Extension, in: The Semantic Web–ISWC 2005: 4th International Semantic Web Conference, ISWC 2005, Proceedings, Springer. pp. 593–606. doi:[10.1007/11574620_43](https://doi.org/10.1007/11574620_43).
- [22] Sousa, D., Couto, F.M., 2020. BiOnt: Deep Learning Using Multiple Biomedical Ontologies for Relation Extraction, in: Advances in Information Retrieval: 42nd European Conference on IR Research, ECIR 2020, Proceedings, Part II, Springer. pp. 367–374. doi:[10.1007/978-3-030-45442-5_46](https://doi.org/10.1007/978-3-030-45442-5_46).
- [23] Studer, R., Benjamins, V.R., Fensel, D., 1998. Knowledge engineering: Principles and methods. *Data & Knowledge Engineering* 25, 161–197. doi:[10.1016/S0169-023X\(97\)00056-6](https://doi.org/10.1016/S0169-023X(97)00056-6).
- [24] Wilkinson, M.D., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.W., da Silva Santos, L.B., Bourne, P.E., Bouwman, J., Brookes, A.J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C.T., Finkers, R., Gonzalez-Beltran, A., Gray, A.J., Groth, P., Goble, C., Grethe, J.S., Heringa, J., 't Hoen, P.A., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S.J., Martone, M.E., Mons, A., Packer, A.L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M.A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., Mons, B., 2016. The FAIR Guiding Principles for scientific data management and stewardship. *Scientific data* 3, 160018:1–9. doi:[10.1038/sdata.2016.18](https://doi.org/10.1038/sdata.2016.18).