DEVELOPMENT PROCESS AND EVALUATION OF THE ONTOLOGY VISUALIZATION TOOL KNOOCKS
A Case Study

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Abstract: Ontologies were becoming popular in various communities and disciplines over the past few years. The reason for their popularity is that they allow to specify concepts and their interconnections of a domain which are understandable by computers and by people. However without visualizations, ontologies - especially large ones - would be hard to comprehend by users. Visualizations are essential because they make ontologies with their structure more manageable. Furthermore, visualization tools are helpful to analyze the interconnections between concepts. For an effective usage of such visualization tools, it is necessary that the design is easy to understand, provides a good overview about the structure and allows fast access to detail information. Furthermore, it is necessary to consider the domain for which the ontology is developed along with its users and their needs. This paper presents the development process of Knoocks – a visualization tool for OWL Lite ontologies – where users were already involved during the process to improve the usability of the tool. Moreover, the presented case study underlines the importance of repeated usability evaluations during the development process to identify weak points of the design and missing features which are relevant for the intended users.

1 INTRODUCTION

Ontologies define concepts and relations which can be used as a skeletal foundation to model and to represent knowledge of a domain (Fensel, 2001; Swartout et al., 1997). OWL (W3C, 2010) is among the most popular languages to describe ontologies. The components of OWL ontologies are: classes, instances and properties. Classes present the relevant concepts and describe the abstract model of the domain. For every class, instances present individual objects of this class and properties represent relationships between instances (object properties) or they relate instances to datatypes (datatype properties). Ontologies make knowledge more accessible and therefore they are becoming popular in various communities and disciplines. The study of (Cardoso, 2007) shows that the vast majority of the participants use ontologies to share and to communicate information between people or software agents. However, ontologies can contain a large number of classes and instances. The results of the Cardoso's survey also show that 44% of the participants worked with ontologies which typically contained between 100 and 1000 classes.

To make ontologies more manageable and understandable for humans, different ontology visualization tools were developed over the past few years (see e.g., (Katifori et al., 2007; Lanzenberger et al., 2009)). Visualizations allow users to see and analyze the structure and dependencies within ontologies in a transparent way or allow them to detect new information which they were not aware of before (Saraiya et al., 2005). Furthermore, graphical representations of ontologies can also be helpful to support users in their decisions. For example, they allow domain experts to control if the concepts and their dependencies are correctly implemented and to decide if modifications will be necessary. For an ef-

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fective usage of such tools, it is necessary to consider requirements which are relevant for ontology visualization (e.g., (Kriglstein, 2009; Noy and McGuinness, 2001)). For example, it is essential that the visualization allows users to efficiently compare subclasses and their instances with each other. In addition to these requirements, it is important to consider potential users and the concepts of the domain during the development process to make sure that the visualization satisfies users' needs, tasks and expectations. Therefore, strategies of human computer interaction (e.g., usability studies) were becoming more and more popular for the evaluation of visualizations over the past few years (Kulyk et al., 2006; North, 2006). The study of (Kriglstein, 2009) has shown that the participants used many different ontology visualization tools for their work. This may be due to the wide variety of applications and forms of ontologies which reflects that different users have different needs and that different domain specific tasks exist. Furthermore, many of the existing tools focus either primarily on the visualization of relationships and properties between classes (e.g., OntoViz) or on the hierarchical structure (e.g., CropCircles) and instances (e.g., treemap view of Jambalaya). This restriction on certain elements of the ontology limits ontology experts but on the other hand allows domain users to use such tools for specifics tasks (as shown in Section 4).

Based on these observations we developed an ontology visualization tool – called Knoocks – to integrate the information of classes, instances and properties in one single tool to allow users to analyze OWL Lite ontologies more easily. For this purpose, Knoocks provides an overview, which allows users to observe relationships on the class level, to analyze classes with their subclasses and to see the distribution of instances within the ontology. In addition to the overview, Knoocks also contains a detail view, which concentrates on the visualization of instances in connection with their classes and properties. Many visualization tools also have a technical interfaces which makes them only understandable for ontology experts which have a lot of experience with these tools (e.g., abbreviations for the drawing settings in OntoViz). However, it is essential to find out what different user groups expect from the visualization and in which context the visualization approach can support them. Our intention was to develop an ontology visualization which is suitable for both groups: ontology experts (users who develop and maintain the ontology) and domain users (users who only want information about the concepts of their domain).

In this paper we present the development process of Knoocks and its evaluation with focus on usability as well as comparison studies with other visualization tools. The remainder of this paper is structured as follows. Section 2 gives a short overview of visualization approaches for ontologies and Section 3 presents the four iterations of the development process of Knoocks. Section 4 presents the evaluation as well as a discussion of the results. The paper is concluded in Section 5.

2 RELATED WORK

A number of visualization tools for OWL ontologies were developed in the past few years. These tools adapted well-known information visualization techniques. For example, several of the existing visualization tools (e.g., TGVizTab (Alani, 2003) and OntoViz (Sintek, 2010) which are both plug-ins for Protégé (Stanford Center for Biomedical Informatics Research, 2010)) present subclass-of relationships and object properties between concepts as node-link visualizations. Node-link representations are an intuitive way to make interconnections within the ontology transparent. However, if the graph contains a large number of classes, instances and relationships, it can happen that the graph becomes overcrowded and therefore the analysis of the ontology is more difficult. In contrast to the node-link representation, container approaches are often used if the focus of the ontology visualization is on the instances and on the hierarchical structure. For example, CropCircles (Wang and Parsia, 2006) visualizes subclasses as circles which are nested inside the circle of their parent class. Similar to the node-link representation, it is not easy for the user to get a quick overview with a container approach if the ontology contains a large number of instances or classes. A combination of node-link approaches and container approaches is another possibility to visualize ontologies. For example, Jambalaya (Storey et al., 2010), which is also a plug-in for Protégé, provides different views with different visualization techniques. In addition to views which represent the relationships between the concepts purely as node-link representation, one view provides the adapted treemap approach of (Shneiderman, 1992) which allows users to rapidly jump between classes or instances. Another view uses a nested graph to visualize classes and their instances and a node-link approach to display object properties.

3 DEVELOPMENT PROCESS

For the development of Knoocks we considered usability and interface design aspects (International Organization for Standardization, 2006; Nielson, 1994; Shneiderman, 1998) as well as specific ontology visualization requirements. These requirements – as listed below – are based on a user requirement analysis with ontology experts (Kriglstein, 2009) and literature studies (e.g., (Noy and McGuinness, 2001)).

Visibility of the Structure. The visualized structure should support effective management of ontologies. It should be possible to compare subtrees with each other and to see the size and depth of each subtree. The visualization should allow users to quickly scan all information with minimal cognitive effort.

Visibility of Classes. Because classes describe the concepts of the ontology, it is essential to get a good overview of them and to understand the relations between the concepts. The visualization should unmistakably distinguish between different classes.

Visibility of Instances. Based on the fact that instances represent data and therefore are often more important to the end-user than the underlying concept, the visualization should also consider instances. It should obviously visualize which classes contain which instances.

Visibility of Relationships. The visualization should clearly show the defined interconnections between the classes and their instances. For good differentiations between the relationships, it is necessary to represent the different types in a distinguishable way (e.g., every type has its own color).

Our main objective in the design of Knoocks was to improve the accessibility of instances and simultaneously allow users to grasp and analyze the structure and interconnections of OWL Lite ontologies. We use a combination of a container approach for instances to represent the hierarchical structure and a node-link approach for object properties. Therefore, the basic structure of Knoocks is similar to the Icicle Plot concept (Kruskal and Landwehr, 1983) and is inspired by container approaches to represent the instances within their classes. The major advantage of the Icicle Plot is that the clustering of objects is easily noticeable (Kruskal and Landwehr, 1983). The study of (Barlow and Neville, 2001) shows that the participants' performance with the Icicle Plot was equivalent to the node-link representations. They stated that the orientation (top-to-bottom or left-to-right) of the Icicle Plot approach was familiar to them, because a similar orientation is also used by common node-link approaches. For the representation of instances, we were also inspired by intended lists, because the list representation is familiar to the user and allows quick scanning of the elements without overlapping. For the representation of non-hierarchical relationships (object properties) we adopted node-link representations. Although they need more space in general than other approaches (e.g., treemap), they are a very intuitive way to show the connections between two nodes. This allows users to clearly differentiate between hierarchical and non-hierarchical relationships. In contrast to existing ontology visualization approaches like, for example, Jambalaya or TGVizTab which either focus on a high-level view of the ontology or on details of individual nodes, it was important for us to visualize both views simultaneously. Although, Jambalaya has the possibility to choose between different visualizations only one visualization is visible at a time and switching between them requires recalculations which can be cumbersome if the ontology is large.

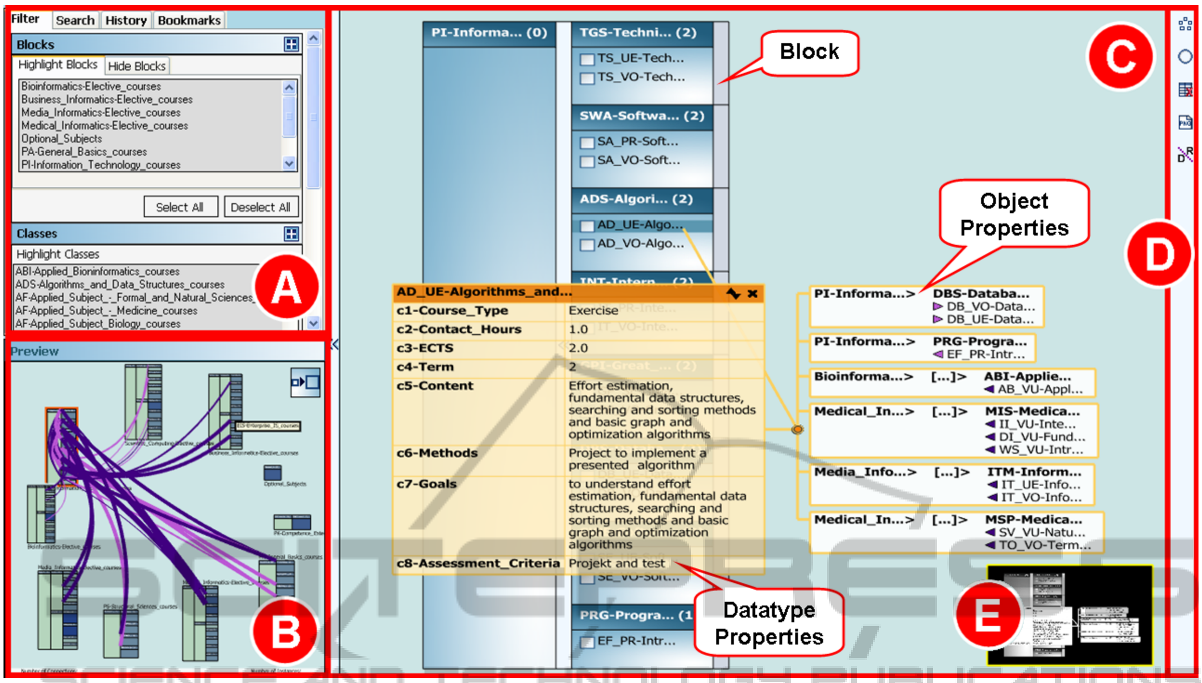
The development of the latest version of Knoocks – as of this writing – required four iteration cycles. The iteration cycles are influenced by the findings of the evaluations that are described in more detail in Section 4.

3.1 First Iteration Cycle

In the first iteration cycle, we concentrated on the design of the representation of subclass-of relationships and instances (for details see (Kriglstein and Motschnig-Pitrik, 2008)). A block (see Figure 1) is the main entity in our approach. Such a block is constructed for each class which is directly connected to OWL:Thing. It is basically a logical container that groups classes, which are connected by subclass-of relationships, in a hierarchical left to right manner. In other words, a class c_s placed to the right of another class c_p is a subclass of c_p. The instances of a class are listed within their class and thereby users see the instances of every class directly without overlapping. If an instance belongs to multiple classes (multiple inheritance) then the instance is listed in each respective class. The size of a rectangle depends on the size of its subclasses and the number of contained instances.

3.2 Second Iteration Cycle

After the basic block structure was well-received by the users (see Section 4) we implemented the two views – overview and detail view. Depending on which of the two views is from more interest, the user can select which one will be displayed in the main window (cf. C in Figure 1) and which one will be



AD_UE-Algorithms_and...	
c1-Course_Type	Exercise
c2-Contact_Hours	1.0
c3-ECTS	2.0
c4-Term	2
c5-Content	Effort estimation, fundamental data structures, searching and sorting methods and basic graph and optimization algorithms
c6-Methods	Project to implement a presented algorithm
c7-Goals	to understand effort estimation, fundamental data structures, searching and sorting methods and basic graph and optimization algorithms
c8-Assessment_Criteria	Projekt and test

Figure 1: The fourth and current version: (A) toolbox which includes the search/filter, history and bookmark functions, (B) preview window, (C) main window, (D) toolbar and (E) thumbnail.

shown in the preview window (B in Figure 1).

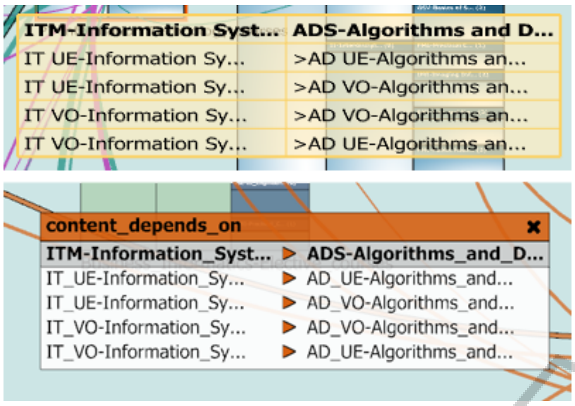
The overview (in Figure 1 currently located in the preview window) shows all blocks arranged in a radial pattern and is well suited to grasp the overall structure of the ontology. Colored curves depict the relations (object properties) between instances. These curves are actually meta-edges, because they bundle relations according to common classes and property type (reflected by the color of the curve) to avoid cluttering the view with a lot of individual curves. The thickness of the curve corresponds to the number of contained relations. If the mouse moves over a line, a relation table with all connected instances appears. To get a better view, it is possible to select which relationship types are visible and which are not.

After clicking on a block in the overview, its detail view is presented in the other window and only relationships, which are relevant for this block, are visible. The detail view only shows one block at a time and therefore can be used to closely examine the individual instances with their associated properties. The detail view shows the instances of every class. Clicking on an instance opens separate tables for datatype properties and object properties (which can also be seen in Figure 1). The object property table allows to directly jump to a connected instance, which means that the detail view is automatically focused on the respective instance. The direction of the relationship is presented as arrow symbol and the color of the symbols reflects the type of the relationship. A thumbnail (see E in Figure 1) of the block in the lower-right corner helps to see the structure of the whole block and allows to navigate quickly within the detail view. The length of texts is restricted to a certain number of characters, otherwise the text is truncated with "..." and tooltips show the full text. Of course, users can switch the views between the large and the small window to enlarge the view, which is of more interest.

Furthermore, the impression of hierarchy – one of the elementary concerns by users – was improved by adding arrows between subclasses. These arrows also allow to expand and collapse the underlying subclasses which further improved the understanding of the left-to-right hierarchy.

3.3 Third Iteration Cycle

Based on the results of the user study of the second version we included several modifications. For example, double-clicking on a block will now automatically open the detail view of this block in the main window. Formerly, this was only possible with a specific *switch* button located in the upper-right corner of the small window. The intensity of the color of a class in the overview reflects the number of contained instances. Another modification is that the relation table can also be pinned down after the user clicks on the associated curve in the overview. The color



ITM-Information Syst...	ADS-Algorithms and D...
IT UE-Information Sy...	>AD UE-Algorithms an...
IT UE-Information Sy...	>AD VO-Algorithms an...
IT VO-Information Sy...	>AD VO-Algorithms an...
IT VO-Information Sy...	>AD UE-Algorithms an...

content_depends_on

ITM-Information_Syst...	ADS-Algorithms_and_D...
IT_UE-Information_Sy...	AD_UE-Algorithms_and...
IT_UE-Information_Sy...	AD_VO-Algorithms_and...
IT_VO-Information_Sy...	AD_VO-Algorithms_and...
IT_VO-Information_Sy...	AD_UE-Algorithms_and...

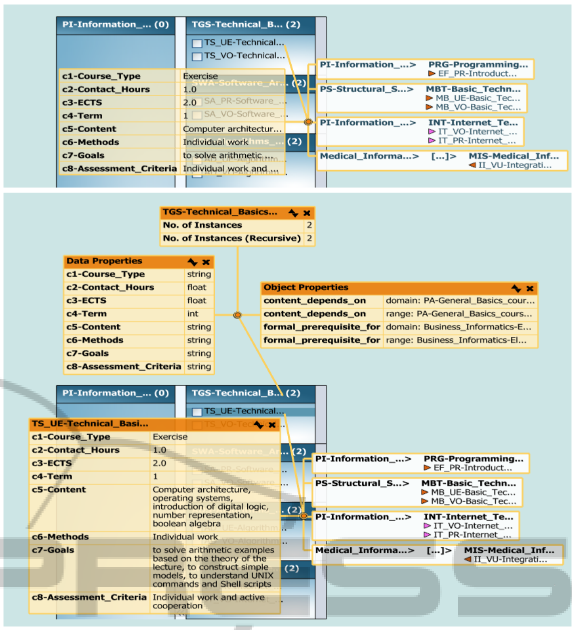
Figure 2: Comparison between the object property table from the second version (top) and the redesigned table from the fourth version (below).

of the relation table header and of the arrows corresponds now to the color of the object property (Figure 2 shows the modifications in detail). Each table was extended with a close button (one of the major confusions in the second version). Furthermore, blocks in the overview can also be individually arranged by the user in case they are not satisfied with the automatic circular alignment.

Additionally, we extended the prototype with history, bookmarks, search and filter functions (see A in Figure 1) as well as a setting window which allows, for example, to set the maximum text length. The history function records every jump from one instance/class to another instance/class and allows users to track their progression through the ontology. Furthermore, bookmarks allow users to select instances that are of interest and to jump back to them at anytime. Additionally to the object property filter, user can also highlight blocks and classes to quickly locate them or they can be hidden if they are not from special interest. Furthermore, a new search function allows users to find specific instances or classes of the ontology. For a thorough description of the third version see also (Kriglstein and Wallner, 2010).

3.4 Fourth Iteration Cycle

In the last iteration cycle, we extended Knoocks with additional features for better user support which will be discussed in detail in the following. One of the main concerns in the evaluation of the third prototype, in regard to the datatype property table was that the table does not list the internal datatype (e.g., integer or string) of a property. This issue has not been addressed by domain users so far but we agree that this is an important information for ontology developers and they can now be accessed via tooltips if the mouse



c1-Course_Type	Exercise
c2-Contact_Hours	1.0
c3-ECTS	2.0
c4-Term	1
c5-Content	Computer architectur...
c6-Methods	Individual work
c7-Goals	to solve arithmetic ...
c8-Assessment_Criteria	Individual work and ...

TGS-Technical_Basics...	
No. of Instances	2
No. of Instances (Recursive)	2

Data Properties	
c1-Course_Type	string
c2-Contact_Hours	float
c3-ECTS	float
c4-Term	int
c5-Content	string
c6-Methods	string
c7-Goals	string
c8-Assessment_Criteria	string

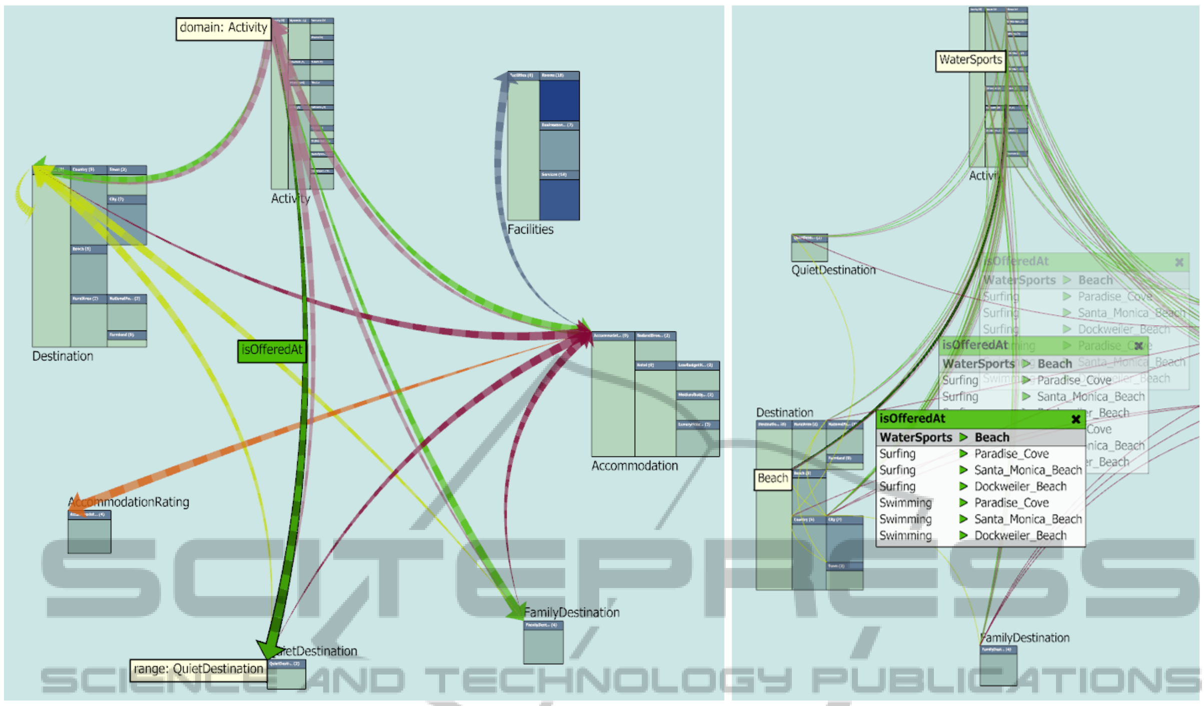
Object Properties	
content_depends_on	domain: PA-General_Basics_cour...
content_depends_on	range: PA-General_Basics_cours...
formal_prerequisite_for	domain: Business_Informatics-E...
formal_prerequisite_for	range: Business_Informatics-El...

TS_UE-Technical_Basi...	
c1-Course_Type	Exercise
c2-Contact_Hours	1.0
c3-ECTS	2.0
c4-Term	1
c5-Content	Computer architecture, operating systems, introduction of digital logic, number representation, boolean algebra
c6-Methods	Individual work
c7-Goals	to solve arithmetic examples based on the theory of the lecture, to construct simple models, to understand UNIX commands and Shell scripts
c8-Assessment_Criteria	Individual work and active cooperation

Figure 3: Comparison between the previous version (above), where text entries were truncated if they exceeded a certain length and the current version (below) which now shows the complete entries. Note also the new header of the property table which now shows the name of the instance or class it belongs to and buttons to collapse and to close the table. To enhance readability the opacity of the tables has been reduced. The lower image also shows the new class information tables which were not available in the previous version.

is placed over the name of the property. The ontology developers also complained that it is not possible to retrieve general information of a class, in particular information about contained datatype and object properties. This information is now accessible by clicking on the class name itself which did not have an effect previously. Furthermore, the internal datatypes for each datatype property are shown. This way it is now possible to inspect all datatype properties assigned to a class, because previously only datatype properties which really had a value assigned were visible in the datatype property table of the instance.

In the previous version long texts were truncated in tables and the complete text was only shown in a tooltip if the mouse was placed over such an entry. Whereas our intention was to avoid that a single table occupies too much space this proved to be inapplicable in same cases, especially if all values of a property start with a certain substring. Users were therefore not able to differentiate the values without accessing the tooltip and therefore had a hard time to remember which property has which value. The revised version gives the user the possibility to expand or collapse the tables to review the complete text or to minimize it



isOfferedAt

WaterSports	Beach
Surfing	Paradise_Cove
Surfing	Santa_Monica_Beach
Surfing	Dockweiler_Beach
Swimming	Paradise_Cove
Swimming	Santa_Monica_Beach
Swimming	Dockweiler_Beach

Figure 4: Left: Domain/range relationships are visualized as curved arrows which point from the domain to the range. The direction is further accentuated by varying the width of the curve from thin (domain) to thick (range). As it is the case with object properties curves (right image), the color reflects the property type. Hovering the mouse over such a curve shows the name of the property, the domain and the range. Right: Clicking on a curve opens a table which shows all relations between instances of the two connected classes. As schematically shown these tables can be moved along the curve.

(see Figure 3 for a comparison). As can be seen in Figure 3, the new table also displays the name of the instance to which the table belongs and, next to it, a close button. These changes were introduced because, if multiple tables were open, users lost track which tables belonged to which entity.

In regard to the overview some minor changes have been introduced. Relation tables can now be moved along a curve which allows users to avoid overlapping to a certain degree and simultaneously ensures that the connection between curve and table does not get broken (see Figure 4, right). These tables can now also be closed by clicking on the respective curve to provide consistency with the possibilities how tables can be closed in the detail view. Furthermore, a button to restore the radial layout has been added to the vertical menu bar. The previous version had a major drawback, because connections between classes were only shown if there existed at least one object property which connected two of their instances. There was no possibility to view the underlying domain/range constraints of the classes. To resolve the problem, another level of abstraction was added to the overview, which shows the domain/range relations as curved arrows (see Figure 4, left).

Another major distinction to the previous version is a context sensitive menu which can be opened in the main window with the right mouse button. This menu makes it, for example, possible to highlight or hide blocks or classes directly in the view and therefore allows users to perform some tasks more fluently because they do not have to switch their attention between the toolbox and the visualization.

Although users were already satisfied with the available search possibilities, they had some suggestions for improving the way the search results are presented. So far, search results were displayed in a listbox with classes written in boldface to easily differentiate them from instances. Clicking on a search result automatically centered the detail view on the respective entity in question and highlighted it with a yellow border. However, if the entity was located in a hidden block nothing was shown in the detail view which led to confusion among users. We now indicate entities located in hidden blocks to remedy the problem. In addition, entities in highlighted blocks or classes are colored to signalize that they may be from greater significance to the user. Furthermore, we refined the navigation of the tool by supporting keyboard shortcuts for important functions, like search and for the new screenshot function. Navigation in the detail view is now also possible by dragging the mouse (and with the arrow keys), because we observed that most users tried at first to navigate this way instead with the thumbnail view in the lower right corner. Finally, the colors of the object properties are now definable by the user, because this way they can accentuate specific properties by assigning appropriate colors.

4 EVALUATION

The main motivation to conduct user tests was to find out more about the usability of the developed prototype in each iteration cycle to make sure that the development goes into the right direction and to compare Knoocks with other visualization tools. The evaluation of the first prototype in the early development phase of Knoocks served as an initial test instrument to find out the advantages and drawbacks of the representation of the hierarchical structure and their instances in comparison with other visualizations techniques. The focus of the user tests of the later prototypes was to detect usability problems and to compare Knoocks with other visualization tools. Furthermore, results of the evaluation were analyzed to find out which functionalities need further improvements and to check if users missed important features.

4.1 Methods

For the evaluation, a combination of the following methods was used: task scenarios, observations in combination with thinking aloud, questionnaires and semi-structured interviews.

To test the efficiency of Knoocks and to compare it with other tools, users had to solve several tasks which were based on scenarios. The focus of one set of tasks was the identification of specific instances and their datatype properties. Another set of tasks concentrated mainly on the dependencies between instances and between classes. To evaluate the structure of blocks, we asked them to identify, which blocks have the most/least classes or which classes contain the most instances. Although certain core tasks stayed the same for each prototype (e.g., which instances has a certain class, find a specific instance) additional tasks were introduced in each iteration because of the increasing number of features (e.g., find a specific instance with a certain datatype property). Users had as much time as they needed to solve the tasks with each tool. While users solved the tasks, they were observed and encouraged to think aloud to make their behavior and decisions more transparent.

In addition to the observation of the subjects and thinking aloud protocols, they were also asked to state how helpful the visualization was for executing each task. For this purpose, we applied a 7-point Likert scale (Likert, 1932) from ”not helpful” to ”very helpful”. Furthermore, subjects were asked to explain their decisions and to give suggestions for possible improvements. After the subjects had finished their tasks, they rated the design of the graphical representation (e.g., bad or good color combination) and they were asked about the strengths and weaknesses of the visualization.

For the evaluation of the second and fourth prototype, we additionally adapted the usability questionnaire, as defined by (Prümper, 1999). The usability questionnaire was originally developed to evaluate software prototypes in regard to the seven dialog principles of ISONORM 9241/110 (International Organization for Standardization, 2006): suitability for the tasks, self-descriptiveness, controllability, conformity with user expectations, error tolerance, suitability for individualization and suitability for learning. In general, the questionnaire includes five items for each of the seven principles and has a 7-point bi-polar format from ”- - -” (very negative) to ”+++” (very positive). Not all items are relevant or meaningful for the visualization and therefore we only used items, which reflect the scope of the visualization.

The motivation to compare Knoocks with other visualization tools was to detect advantages as well as drawbacks between the tools. Furthermore, it was interesting to analyze how well the users interacted with the different visualization approaches. For the comparison studies, we have chosen the following visualization approaches: CropCircles, TGVizTab, OntoViz and the nested graph view of Jambalaya. CropCircles is a container approach, which represents the subclass-of relationships between classes as nested circles. Our motivation to compare Knoocks with CropCircles was the different representation of the hierarchical structure of the classes. In contrast to CropCircles, TGVizTab and OntoViz visualize the structure of ontologies as node-link representation. Both approaches represent classes and instances as nodes and subclass-of relationships and the object properties as edges. The reason to compare Knoocks with Jambalaya was their similarity, because the nested graph view of Jambalaya presents the hierarchical structure with its instances as container approach and the object properties as node-link representation. To make the results comparable, the subjects solved similar tasks for each tool. Additionally, the order of tasks and tools was changed for each testing session to avoid that a specific order influences the results.

Before the participants started with the tasks, they got a short introduction to the most important functionalities of the tools. After the subjects had finished their tests, we asked them which visualization they preferred in regard to their expectations and user friendliness (specifically, which tool was most helpful, which one was the most understandable tool and which tool met their expectations best).

4.2 Sample

For the evaluations we used an ontology that defines a bachelor of computer science curriculum which includes 86 classes, 122 instances, 2 object properties and 8 datatype properties. We used such a kind of ontology because we were able to get a large number of participants in that particular domain. Contrary, it was very hard to get participants in other domains, especially experts (e.g., in medicine). Furthermore, it supported the ongoing efforts at our university to make the curriculum structure more transparent for students and lecturers.

Motivated to evaluate the fundamental idea and to detect misinterpretations or unclear elements of the visualization, we tested Knoocks with potential users of the domain and with ontology developers. In each iteration cycle we used different subjects to make sure that previous experiences with Knoocks do not influence the results.

First Iteration Cycle. The findings of the first evaluation are based on six students and the testing sessions for each participant took about 40 minutes. For the comparison study in the first iteration cycle, the participants solved similar tasks with CropCircles and the nested graph view of Jambalaya.

Second Iteration Cycle. The results of the second evaluation are based on 22 participants (15 students and 7 lecturers). The testing sessions for each participant took about 90 minutes.

Third Iteration Cycle. Three ontology developers evaluated the prototype in regard to usability and functionality. Although this is a rather small number of participants, we received valuable qualitative feedback and the testing sessions for each participant took about 180 minutes. For the comparison study, we chose TGVizTab and the nested graph view of Jambalaya.

Fourth Iteration Cycle. The prototype were evaluated by 16 subjects (9 students and 7 lecturers) and the testing sessions for each participant took about 120 minutes which include also the comparisons with Jambalaya and OntoViz.

4.3 Results

In general, the findings of the observation and thinking aloud protocols showed that the concepts of Knoocks and especially the hierarchical layout of the blocks was clear and immediately understandable. Furthermore, they rated the color combination as good and found the design well-balanced. The following strengths of Knoocks were named most frequently during the user tests:

Clear Overview and Detail View. The layout of blocks allowed to quickly see the subclasses and the instances of classes. Furthermore, the switching between the overview and the detail view, the circular arrangement of blocks in the overview and the visibility of both views at the same time were named as helpful to get a good overview about the ontology.

Easy to Learn and Understand. The participants found Knoocks and its functionalities intuitive, easy to learn and to memorize.

Clear Structure and Relationship Views. The representations of object properties in the overview was clear and gave a fast impression of the relationships of the ontology. The visualization of properties of an instance in the detail view gave them a clear overview about the dependencies between the instances.

Additional Support for Analysis. The different filter and search possibilities, as introduced in version three, were mentioned as very helpful, e.g., to find specific instances or classes or to set the users' focus on specific blocks or object properties. The visual coding was named as a further strength, e.g., the color coding to present the number of instances or the thickness coding to visualize the number of connections between classes.

These strengths conform with the expectations of almost all participants which they have in regard to ontology visualization tools and are also in accordance with the revealed user expectations in (Kriglstein, 2009).

The following sections discuss the findings of the usability study and comparison study between the three tools in detail.

4.3.1 Usability Evaluation

Although the results of the user tests showed that the subjects rated Knoocks in each stage predominantly positive, the modifications, which were based on the detected usability problems, were the reasons for noticeable improvements in Knoocks' usability in each

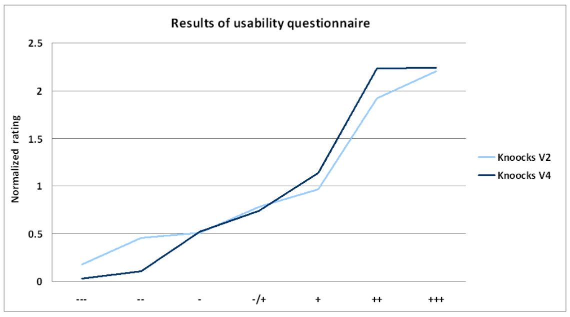


Figure 5: Normalized results of the rating of the seven dialog principles from ”- - -” (very negative) to ”+++” (very positive) for the second and fourth prototype.

stage. The findings which are listed below are not exhaustive but were the most relevant ones for the further development process.

First Iteration Cycle. The elementary problem was that the direction of the hierarchy was ambiguous. However, the block structure allowed them to get a quick overview and to locate instances without problems.

Second Iteration Cycle. During the second evaluation we observed that users tried to double-click on a block to enlarge it. This maybe the case, because the icon of the switch-button was not clear enough for many participants. However, they appreciated the possibility to choose which view is shown in the main window. It was intuitive for them, to click on an instance to retrieve detail information (object and datatype properties). Though, most of the users had problems to close the details again, because there was no explicit close button. Most of them found the truncated texts annoying, especially if multiple instances began with the same letters as it was the case in our test ontology. The representation of properties was well received by the participants, because it allowed them to compare different instances in regard to their properties. This was further supported by the possibility to drag and drop these tables. One of the most missed features was a search function, because they stated that currently the tool is nice for browsing but is not suitable for finding a specific instance. As further improvement, they stated they would like to be able to also move/highlight/hide blocks in the overview.

Third Iteration Cycle. The changes were well received by the users. However, ontology experts complained that information about the internal types (integer, string, etc.) of datatype properties is missing. They also missed general information about a class, like the number of contained instances or which object properties are supported by this class.

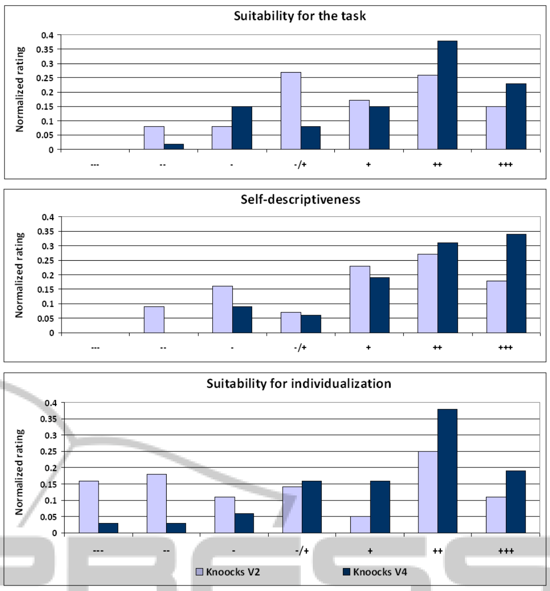


Figure 6: Normalized values of the rating of three dialog principles for the second and fourth version.

The search results were partly confusing because the list representation made no difference between hidden, highlighted or normal blocks.

Fourth Iteration Cycle. Although the node-link representation of object properties and that the thickness of their curves reflects the number of connections was clear, several subjects stated that the thickness alone is insufficient with increasing number of represented relationships. Therefore they would prefer to additionally see the number of connections as label for each curve. Furthermore, they found that the color coding of classes to show the number of instances is a good way to quickly get an overview of the distribution of instances within the ontology. The possibility to jump between instances and their highlighting was noted as very helpful. However, more than half of the subjects missed the highlighting of instances or classes in the detail view, because the time, which showed the highlighting, was too short or the instance in question was occluded by open properties. All participants found the search function very helpful, especially because it allowed them to find instances or classes which conform to a specific datatype property (e.g., to find all courses which were held in the third term).

The improvement of the usability was further underlined by the results of the usability questionnaire, as can be seen in Figure 5. A closer look at the different dialog principles shows that the participants rated the fourth prototype better than the second, especially in regard to the following three principles (see also Figure 6 for details):

Suitability for the Task. Reasons for the better rating are the new filter and search function. Moreover, the handling of the fourth version was rated as easier, because of the additional support of keyboard shortcuts, the modifications of the property representations and the context sensitive menu.

Self-descriptiveness. Relevant improvements, amongst others, are that the complete text in the datatype property tables is now visible at first glance, that the name of the instance along with a close button is presented in the property table and that a double click on a block automatically opens the detail view in the main window.

Suitability for Individualization. The possibility to move blocks and relation tables individually, to customize colors for object properties and to set the maximum label length are reasons for the better rating of the fourth version.

4.3.2 Comparison Study

For the comparison studies different kind of tasks had to be solved by the participants. This would include tasks like: find a specific instance, identify dependencies of an instance, find out which instances belong to a certain class or identify to which class a specific subclass belongs to. Table 1 summarizes which Tools have been used for the comparison in which iteration of the development process.

The comparison studies showed that most subjects found that Knoocks was easy to learn and provided a better general overview about the ontology and its object properties than the other tested tools. For example, the hierarchical representation of the classes as nested circles in CropCircles was for the subjects hard to understand in the beginning and the performance to find a specific class was lower as with Jambalaya or Knoocks. Although the participants liked the design of Jambalaya, it was rather difficult for them to get a general overview and to find specific classes or instances in case of the nested graph layout. Reasons were that the labels of the instances and classes overlapped and the zooming function was rated as difficult to handle. However, zooming was necessary to compare different subclasses from different levels. Furthermore, the subjects found it harder to distinguish between hierarchical and non-hierarchical relationships in TGVizTab, because of missing visual differentiations. The missing visual differentiations between non-hierarchical relationships were also the reason why the subjects had problems to distinguish

Table 1: Tools which have been used for the comparison of Knoocks at the different stages of development. In iteration 2 no comparison study was carried because the evaluation concentrated mainly on usability issues.

Iteration	CropCircles	Jambalaya	OntoViz	TGVizTab
1	×	×		
3		×		×
4		×	×	

the different object property types in OntoViz. Furthermore, they found it hard to memorize the abbreviations for the drawing settings in OntoViz.

In summary, the comparison studies showed that tools with a rather technical interface (OntoViz and TGVizTab) had been rated lower than the ones with a more accessible interface (Jambalaya and Knoocks). This was also confirmed by the ranking of the tools in regard to user friendliness and expectations which yielded the following results the last iteration circle. 79% ranked Knoocks on the first place, whereas 18% ranked Jambalaya on the first place. However, 78% voted Jambalaya on the second place followed by Knoocks with 11%. OntoViz on the other hand was ranked on the third place by 95% of all participants.

5 CONCLUSIONS

Visualizations support users to generate knowledge about the presented data and make the ontology more understandable and manageable. To make the work with ontologies more effective, the needs of users play an essential role for the design of the visualization. Usability evaluations of visualizations help to get feedback what works well and what needs further improvements. However, only one usability test at the end of the development process is often not sufficient. The involvement of potential users during the development process allowed us to integrate feedback immediately which was very valuable to keep the development on the right track.

This paper presented the development process of the ontology visualization tool called Knoocks and its evaluation with focus on usability and comparison studies with other visualization tools. Knoocks allows users to analyze the structure of classes with their instances and properties in one single tool. The tool is primarily developed for users who want information about concepts of their domain as well as for users who develop and maintain the ontology. The case study demonstrated that modifications based on the results of the user tests for each iteration cycle of the development process had a positive impact on the usability. This significantly simplified working with the visualization tool. The comparison between Knoocks with CropCircles, OntoViz, Jambalaya and TGVizTab showed that the handling of OntoViz caused most problems. Although, participants liked the nested graph view in Jambalaya, most of them preferred the layout of Knoocks. Reasons were that Jambalaya only visualizes one set of subclasses or instances for a class in more detail and that the visualization easily overcrowds with an increasing number of object properties. One participant also explicitly noted that the handling and functionalities of Jambalaya seemed more complex than the handling and functionalities of Knoocks. The results of the comparative study with these tools emphasize the significance of the usability in regard to the handling and rating of the tools.

One of our next steps is to verify how the requested functionalities or design elements which were difficult to understand (e.g., to add labels for showing the number of connections between classes in the overview) in the fourth prototype can be included in the next version. Knoocks is currently being developed as a plug-in for Protégé to combine our visualization approach with the editing functionality of Protégé.

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