Visualization and Interaction for Ontologies and Linked Data – Editorial

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The Semantic Web enables intelligent agents to create knowledge by interpreting, integrating and drawing inferences from the abundance of data at their disposal. It encompasses approaches and techniques for expressing and processing data in machine-readable formats. All these tasks demand a human-in-the-loop; without them the great vision of the Semantic Web would hardly be achieved. Meanwhile, visual interfaces for modeling, editing, exploring, integrating, etc., of semantic content have not received much attention yet.

This special issue draws the community attention toward visualization and interaction techniques for ontology engineering as well as the production and consumption of Linked Data in traditional and novel interaction contexts.

Current Topics

The field of visualization and interaction for ontologies and Linked Data has received more and more attention during the recent years. In this editorial we have selected[1] a number of current topics that we discuss and connect to the papers that compose this special issue.

Cognitive Support

While cognitive aspects are of interest, publications rarely and only indirectly address them. Visual representations leverage humans' most powerful perceptual channel—the visual system—and play a crucial role in understanding complex data and acquiring insight. In addition, interacting with visualizations is indispensable in order to facilitate understanding and to overcome limitations of the visual representations. As other knowledge-intensive areas, the Semantic Web deals with inherently intricate content. This poses high demands on its users in their tasks, such as modeling, formalizing, editing, verifying, sensemaking, exploring, etc., and involves a variety of cognitive processes—perception, attention, working memory, reasoning, etc. The importance of cognitive aspects of user activities was reflected in a Dagstuhl seminar on "Cognitive Approaches for Semantic Web" held in 2012 and summarized by Gentner et al. (2012). They point out that *"Cognitive aspects emerge as an essential ingredient for future work on knowledge acquisition, representation, reasoning, and interactions on the Semantic Web."*

Cognitive processes could be efficiently supported by user interfaces encompassing well-designed visual representations and interaction techniques. We believe that providing carefully designed user interfaces, visual representations and interaction techniques will foster the wider adoption of the Semantic Web and semantic technologies, and likely lead to higher-quality results in different applications employing ontologies as well as proliferate the consumption of Linked Data. In order to provide efficient support for developers and users of semantic content, we need to draw upon approaches and techniques from relevant areas. As pointed out by Dadzie and Pietriga (2017), there are still a number of visualization and interaction techniques that proved effective but have not yet been considered in the Semantic Web area.

While the need for applying cognitive approaches to the Semantic Web has been recognized, only a few works, mostly in the field of ontology engineer-

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[1]The selection is partly based on discussions in one of the venues where researchers in this field meet, i.e., the VOILA! workshop series. Three workshops of the VOILA! series took place in 2015-2017 (Ivanova et al. (2015a, 2016, 2017)) in conjunction with the respective editions of the International Semantic Web Conference (ISWC). The fourth edition of the workshop—VOILA! 2018 (http://voila2018.visualdataweb.org, Ivanova et al. (2018))—co-located with ISWC 2018 is on its way.

ing, have undertaken the endeavor to address this challenge. Early works by Ernst et al. (2005) and Falconer and Storey (2007) (extended in Ivanova et al. (2015b)) discuss the need to provide cognitive support during ontology modeling and mapping. Focusing on ontology modeling, Ernst et al. (2005) emphasize three broad activities which could be efficiently supported by means of visualization and interaction techniques. These include navigation of ontologies to support understanding, discovery and search, modeling to support development and maintenance of knowledge bases as well as verification to support visual inspection of the developed model. Ten years later, Vigo et al. (2015) studied ontology authoring activities by analyzing usage logs and eye-tracking data. Their study provides similar categories: exploration of the ontology hierarchy for understanding and editing purposes and for inspecting the consequences of editing actions after a reasoner has been run. Another work by Vigo et al. (2014) identifies pitfalls in the ontology authoring process by interviewing 15 ontology experts working mostly with life science ontologies. Some of the pitfalls recognized in it are in connection to the aforementioned topics and include exploration and navigation of the ontologies, ontology building, debugging and reasoning. In order to support verification of authoring actions, Horridge et al. (2013) study the cognitive complexity of justifications of OWL entailments and Warren et al. (2014) investigate cognitive difficulties in understanding often-used Description Logics features.

In the present special issue, the work by Matentzoglu et al. addresses the topic of verification of authoring actions by explicitly presenting their consequences to ontology authors.

Who are the Users?

Another important topic deals with the issue of the target users of the tools developed by the Semantic Web community. As ontologies and Linked Data are being used in more and more application areas and by users with increasingly diverse backgrounds, user interfaces adapted to the needs of different user groups are in demand (e.g., Dragisic et al. (2016)). While a number of user interfaces have become available in the past years, they are rarely based on analytical or empirical studies of user activities, task analysis or advances in cognitive sciences, which can prevent their potential in supporting the interaction between users and the Semantic Web to unfold. While recruiting actual users is infamously difficult, a variety of user studies at the different stages of UI development are needed—observational studies, interviews, etc.—to supply requirements for the tools we build and to analyze the benefits from the proposed solutions. Similarly to Dadzie and Pietriga (2017), who noted a growing number of user interface evaluations, we observed an increasing number of studies in the course of the development of the workshop series. However, conducting in-depth empirical user evaluations is still a challenge in front of the Semantic Web community. Existing evaluations are often not conducted with intended users and have flaws in their set-ups and reporting protocols, which prevents the demonstration of the benefits from the proposed solutions and hinders their adoption.

While user studies are essential and irreplaceable for understanding user activities, a convenient approach to gather data and obtain insights of actual user actions is to examine usage logs. Such studies could draw data from both ongoing and completed real-world ontology engineering projects and allow for studying behavior of more users and over longer time periods than would be involved in observational user studies. Furthermore, the analysis of usage logs provides a means for studying how users collaborate being a topic addressed by only a few works in the Semantic Web community.

In recent years, several works employ usage logs to provide insights into the authoring process of biomedical ontologies. These studies apply clustering algorithms and Markov chains to analyze authoring actions during several collaborative projects. Falconer et al. (2011) distinguish different user roles by the level and number of locations in the hierarchy where editing actions take place. Strohmaier et al. (2013) observe that editing actions follow the ontology hierarchy in a top-bottom manner with frequent changes performed at different levels in the different projects. Findings by Walk et al. (2014, 2015) further show that ontologies are changed in a top-bottom and breadth-first manner. These results corroborate the findings from the eye tracking study of Vigo et al. (2015) mentioned above, which found that the class hierarchy receives 45% of user's attention during exploration, editing and reasoning activities.

While the above studies consider changes in single ontologies, Walk et al. (2017) investigate the usage of the BioPortal repository consisting of a large number of biomedical ontologies. It aims to reveal how such repositories are used and identifies user groups based on the BioPortal services users engage with. The work by Kamdar et al. in this special issue follows the latter thread of research by investigating the connection between the usage of BioPortal services for exploring and reusing ontologies.

Semantic Technologies in Support of Visual Exploratory Analysis

A topic that is receiving attention currently is the application of semantic technologies to the visual (exploratory) data analysis workflow. In the Big Data era, the abundance of data sources enables data-driven decision making. Applying semantic technologies could improve the organization, integration and (visual) analysis of their heterogeneous content. Carefully-designed visualizations are a means for effective visual analysis, hypothesis development and confirmation as well as insight acquisition. Semantic technologies can support all stages of the *data state model* of information visualization developed by Chi (2000). A similar model, called information visualization reference model[2], has been introduced by Card et al. (1999). In the following, we adopt the terminology used in the latter model.

The information visualization reference model provides a general framework consisting of three transformations, which describe a sequence of steps for turning raw data into interactive visualizations. During the first transformation—*data transformation*—, data needed for the subsequent analysis is extracted from *raw data* into *data tables*. This is achieved by addition of structure and relations in the data, recording of meta-data, dealing with missing and erroneous values, deriving new data values from existing ones, etc. At this step, ontologies can provide a shared representation of the information space by supplying means for organizing and integrating data from various heterogeneous data sources and could guide information extraction and enrichment, and data cleansing.

Once necessary data become available, selected parts of the *data tables* are encoded using visual features, such as graphical primitives (dots, lines, areas, etc.), their properties and spatial location, into suitable *visual structures*, depending on the visualization tasks and context. This happens during the *visual mapping* transformation. At this step, semantic technologies can provide templates with (predefined) queries at different level of detail, which focus on desired parts of the information space and define visual features and metaphors according to selected data types and values. An early work by Pietriga et al. (2006) introduces Fresnel—an RDF vocabulary for the presentation of semantic content. It is based on two concepts: *lenses* which are used to select resources and properties for presentation and *formats*—to style and format extracted content. In an ontology-based data access scenario, Giese et al. (2015) describe the OptiqueVQS visual interface for building on-demand queries using a domain ontology. The system then builds SPARQL queries which are translated and executed over various data sources mapped to the ontology.

During the final transformation—*view transformation*—graphical *views* are assembled, by selecting from possible *visual structures*, and coupled with interaction techniques, such as brushing and linking, zooming and panning, details-on-demand, focus and context, etc. This allows users to extract further content from the views according to their tasks. Semantic technologies can support the adaptation and customization of the *views* according to the users' profiles, tasks and contexts. For instance, Paulheim and Probst (2010) propose an approach for the ontology-based personalization of the appearance of user interfaces. The Linked Data Visualization Model presented by Brunetti et al. (2013) applies and extends Chi's data state model to the generation of interactive visualizations from Linked Data. This work takes benefit from the RDF representation of the data and employs ontologies to determine compatible components during and between the transformations and to customize the resulting visualizations. A work by Khalili et al. (2016) aims to facilitate Linked Data visualizations development by extending the concept of Web Components. The authors propose Linked Data-driven Web Components where the RDF data model is also used to describe their content, metadata, scope of user interactions and to support customization.

After assembling initial views, users can interact with them and change the the parameters of the transformations. This allows for interactive visual exploration of and insight acquisition from the underlying information sources in support of data-driven decision making. Semantic technologies can be used to guide the exploration by following relationships, filtering out irrelevant content and

[2] Also called *information visualization pipeline* in the literature.

providing views at different levels of granularity. They can support the discovery of regions of interest, trends and clusters in the data as well as the identification of data with similar properties. Paulheim and Probst (2010) envision several possibilities for ontology-enhanced user interfaces and list ontology-based browsing (i.e., faceted-browsing, semantic overlays) and user input support (by auto-complete techniques, reducing selection choices and query construction; also seen in the aforementioned OptiqueVQS approach). In this spirit, Dadzie et al. (in this special issue) demonstrate the benefits from the application of semantic technologies to visual exploratory data analysis and knowledge discovery in the context of a skill demand analysis.

Publishing Data on the Web

Making data stored in various formats available to Semantic Web applications by publishing them in RDF format or supporting ontology-based data access (OBDA) has been attracting significant attention. This is often achieved by employing a mapping language which is used to define rules for converting the content of data sources into RDF or creating mappings to ontologies and thus enabling SPARQL queries. A few years ago, Michel et al. (2014) surveyed approaches for converting content stored in relational databases into RDF and studied seventeen tools comprising of both tools compliant to the W3C R2RML recommendation and tools implementing their own mapping languages. At the time of the survey, only one graphical editor, developed by Sengupta et al. (2013), was available to support the definition of R2RML mapping rules. It provides a wizard to guide users through a sequence of steps when creating mapping rules—from the selection of the data source and logical map to the creation of subject and predicate-object maps. Since then, developing visual interfaces for generating Linked Data (from data encoded in various formats) and enabling SPARQL querying has attracted significant attention.

Visual mapping editors often implement the W3C R2RML recommendation, and follow one of the following approaches for representing the content of the data source, ontology and mappings. One popular approach, adopted by Lembo et al. (2014), Blinkiewicz and Bąk (2016), and Sicilia et al. (2017) among others, represents the mapping rules as a graph with the data source and ontology in different regions of the graph or in separate tabs. Semi-automatic approaches generate an initial set of mappings, which the user can then validate and complete. The mappings are presented in a list in Ultrawrap by Sequeda and Miranker (2015) and as a tree with nodes above matching table columns (which represent attributes of the data source) in Karma by Knoblock et al. (2012). Recently, a block metaphor approach has been proposed by Crotti Junior et al. (2017) which allows only compatible blocks (representing R2RML statements) to be combined. The block metaphor approach was earlier explored by Bottoni and Ceriani (2015) for building SPARQL queries. In this special issue, Heyvaert et al. discuss requirements and propose a graph-based visual notation for representing R2RML mappings—MapVOWL. The authors then conduct two user studies to compare the development of mapping rules with the MapVOWL notation, implemented in their RML Editor Heyvaert et al. (2016), (i) to creating them directly and (ii) to a form-based approach (which, similarly to step-by-step wizards, requires the user to enter or select from possible values).

This Issue

The call for papers was published at the end of May 2016, and 16 manuscripts were received. After a thorough review by the guest editorial board, four manuscripts were accepted for inclusion in this special issue. Each of them addresses one of the topics discussed above.

We see the work of Matentzoglu et al. (in this issue) in the light of cognitive support provided by ontology engineering tools—supporting verification of authoring actions—which is important for understanding consequences of user actions and for detecting and resolving errors in ontologies. Developing ontologies is a difficult and error-prone undertaking due to the complexity of knowledge representation languages. Users typically have problems understanding certain language features and justifications of OWL entailments. As a result, the addition and removal of axioms may lead to unintended consequences, which poses a significant cognitive challenge for developers to identify, as tools rarely provide adequate feedback. Exploring the inferred class hierarchy after running a reasoner is a common activity for examining the consequences of ontology changes.

In their work, Matentzoglu et al. explore the hypothesis that explicitly presenting entailments of ontology changes improves the users' understanding of their authoring actions in comparison to presenting the inferred hierarchy only. The authors provide a rationale for the choice of entailments to present, and developed a Protégé plugin—Inference Inspector—which depicts the entailments of changes conducted between two reasoner runs. An exploratory user study and a controlled experiment provide evidence that explicitly depicting the set of entailments significantly improves the understanding of consequences of user actions w.r.t. correctness and speed. The approach is most beneficial for verifying changes in existing restrictions and identifying sources of unsatisfiability.

Another work which addresses user support during ontology engineering activities studies the behavior of ontology users when exploring and reusing ontologies in a large repository. Kamdar et al. investigate how BioPortal users explore ontologies through the BioPortal Web UI, query them by the Bioportal API and reuse them in a large scale study encompassing BioPortal logs over several years. The authors hypothesized that there is an overlap between the classes explored with the WebUI and those accessed through the API due to users first exploring ontologies (via the WebUI) to determine their use and then querying and reusing the same classes (via the API) in other ontologies. The study was carried out by means of several visualization techniques in order to support insights at different level of detail. Contrary to the expectations, the results suggest that the exploration and query behaviors do not inform reuse in other ontologies. This observation could be explained by the type of most-often reused classes which are either at an abstract level or from upper-level ontologies. Another finding reveals that there is minimal overlap between the classes accessed via the WebUI and the API.

Dadzie et al. focus on a rarely addressed topic and demonstrate the potential of applying semantic technologies for supporting the transformation of raw data into interactive visualizations and follow-up visual exploratory analysis in a skill demand study. The authors choose the Data Science domain motivated by its broad and imprecise skill range and the recent increase of data scientists jobs. The study aims to reveal the EU market demand for data scientists, and the extent to which it is fulfilled by skills present in practitioners with relevant occupations. It targets data science practitioners with technical and complementary skills as well as non-technical users familiar with the requirements of big data analysis. The authors formalize and revise their initial requirements at user, data and task level, presented at VOILA! 2015, in the Skills and Recruitment Ontology (SARO). SARO was used for structuring the domain knowledge, information extraction and enrichment of necessary data which were collected from multiple job portals and encoded in RDF. In order to support the exploration process, several complementary visualizations—timelines, small-multiples, parallel coordinates—were implemented to provide overview, enable identification of trends and regions of interests, and obtain insight. Additionally, node-link diagrams, based on the SARO ontology, were created to facilitate the visual identification of relationships between skills. Following an approach similar to Fresnel's lenses and formats two templates were defined for higher level concepts—one consisting of a SPARQL query to extract relevant resources and another to specify their visual presentation. The initial prototypes were evaluated as a part of the development process, and the evaluation results were incorporated into the successive development workflow. The applicability of the resulting tools and visualizations was assessed by conducting two heuristic evaluations with four domain experts using a think-aloud protocol, post-study interviews and the SUS questionnaire. The article details the use cases under consideration, the SARO ontology, the information extraction and the visual exploration performed by the study participants, and their feedback.

Heyvaert et al. address the issue of making data encoded in various formats accessible in the Semantic Web. They present requirements and a graph-based visual notation for mapping rules—MapVOWL—, which aims to support in the generation of Linked Data from raw data. The authors further discuss requirements for a visual editor of mapping rules, and present RMLEditor, which supports the visual development and modification of rules and the transformation of data values. The article details two user interface evaluations that were conducted to study the development of mapping rules with different approaches. The first study compares the development of mapping rules by employing either the MapVOWL visual notation or the RML language directly. The participants perform slightly better when using the RML language, but most of them prefer the MapVOWL notation for editing and visualizing the rules. The second study focuses on editing mapping rules and compares the graph-based approach of RMLEditor to the form-based approach implemented in another RML editor called RMLx Visual Editor. The results show that the users of RMLEditor are able to complete more rules and perceive their development as less difficult than the users of RMLx Visual Editor.

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Guest Editorial Board

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