Visualizing OWL and RDF: Advancing Ontology Representation for Enhanced Semantic Clarity and Communication

Giulia Biagioni[a]
Unit ISP, Netherlands Organisation for Applied Scientific Research (TNO), New Babylon, Anna van Buerenplein 41a, Den Haag, The Netherlands

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Abstract: This position paper advocates for the development of advanced visualization tools specifically designed to represent the full range of expressiveness conveyed by the vocabulary terms of OWL and RDFs. It highlights the urgent need for a standardized way to visually refer to these vocabulary terms, addressing current challenges in ontology visualization. The paper outlines the significant benefits that such tools and initiatives will deliver, including enhanced clarity, improved communication among stakeholders, and more efficient management of semantic data. By standardizing visual representations, the paper argues for a more intuitive and accessible approach to interacting with complex semantic structures, ultimately facilitating better understanding and broader adoption of semantic web technologies.

1 INTRODUCTION

In the landscape of European Union initiatives, including the establishment of data spaces and Internet of Things (IoT) driven frameworks for smart environments, ontologies have emerged as essential instruments (Corcho and Simper, 2022)(Commission, 2022). These frameworks are instrumental in standardizing data across a myriad of sectors, enhancing interoperability, ensuring regulatory compliance, and augmenting the functionality and integration of smart technologies. This integration fosters interoperable and efficient communication among devices. Despite the widespread acknowledgment of their utility and the broad adoption across various domains, a significant challenge persists: the lack of efficient visualization tools for examining the logical structures of ontologies defined through RDFs (Resource Description Framework) and OWL (Web Ontology Language) standardized semantics [1].

Current visualization tools fall short in enabling users to effectively and thoroughly explore the intricacies of ontology structures, encompassing their axioms, rules, and taxonomical classifications (Dudás et al., 2018). This gap in technological capability significantly impedes users' ability to conduct comprehensive inspections, which are critical to verifying the consistency and accuracy of semantic constructions within ontologies. Moreover, this situation is compounded by the limitations inherent in existing RDFs and OWL-based reasoners, which often struggle to identify contradictions or process inferences with the necessary precision for ensuring semantic consistency. Adding to these challenges is the lack of a standardized approach for visually representing the vocabulary and symbols associated with OWL and RDFS. This absence of a uniform visual language hinders effective communication and comprehension among stakeholders who interact with these semantic systems.

There is a pressing need not only for improved visualization tools that can adeptly handle the complexity of ontological structures but also for the development of a cohesive visual language that can standardize the representation of semantic constructs. Such advancements would greatly enhance clarity and usability, enabling users to more effectively engage with and utilize semantic technologies in their respective fields. This position paper will delve into these challenges and propose strategic pathways to address these critical gaps. The content of this paper is presented by respecting the following order. Section 1

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[a] https://orcid.org/0000-0002-9005-7945

[1] For RDFs and OWL semantics cf. respectively: https://www.w3.org/TR/rdf-schema/ and https://www.w3.org/TR/owl-guide/

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delineates the introduction. Section 2 addresses the current state of ontology visualization tools and the challenges faced by ontology engineers. Section 3 investigates the shortcomings of reasoners in analyzing ontological structures and provide support to ontology engineers in assessing the logical consistency of the ontology. Section 4 discusses how semiotic principles can enhance ontology visualization by creating intuitive and meaningful representations that facilitate better communication and understanding. The conclusion emphasizes the critical need for integrating semiotic principles into visualization tools as the semantic web grows, advocating for both the development of visualization tools targeting the semantics of OWL and RDFs and the creation of a standardized visual language (i.e set of symbols used in visualization tools for ontologies) to refer to them.

2 STATUS & CHALLENGES

In the field of the semantic web, no visualization tool or method has yet been universally adopted as the standard, according to Dudas and colleagues (Dudás et al., 2018). This lack of a standard can be attributed primarily to two main reasons. Firstly, there is no 'one-size-fits-all' solution that caters to the varied requirements of different users. Secondly, there has been minimal progress in this area since 2007.

Dudas et al. (Dudás et al., 2018) identify four primary high-level use cases for ontology visualization tools: editing, learning, inspecting, and sharing. Visual editing involves generating an ontology script automatically from a diagram, a feature particularly useful for users unfamiliar with RDF(S) and OWL syntax. Visualization tools also play a crucial role in learning and inspecting ontology structures. These activities are primarily aimed at ontology engineers who need to identify and rectify semantic errors, inconsistencies, and contradictions. Finally, sharing knowledge representations visually provides an effective means to quickly communicate the scope of ontologies, thereby enhancing understanding and collaboration.

Visualization tools offer a range of benefits that can significantly enhance information processing and management (Bernasconi et al., 2023). By increasing cognitive memory and optimizing resource processing, these tools make it easier and faster to access and assimilate information (Skulmowski and Xu, 2022). They simplify the search for information and enhance the ability to detect patterns, thus facilitating quicker and more effective decision-making. Visualization tools also support perceptual inference operations and improve attention mechanisms, which are crucial for monitoring complex systems. Additionally, these tools encode information in a format that is easy to manipulate, allowing users to handle and analyze large datasets efficiently. They provide a comprehensive overview while enabling detailed exploration, helping users to maintain a broad perspective even as they delve into specific data points. Furthermore, visualization tools are invaluable for tracking various elements and activities, and they excel at producing abstract representations of scenarios by selectively omitting and emphasizing certain pieces of information, thereby simplifying complex situations.

The visualization of ontologies, encompasses a diverse array of methods each suited to specific use cases, including indented lists, node-link visualizations, force-directed layouts, tree layouts, radial layouts, circle layouts, inverted radial tree layouts, Euler diagrams, treemaps, 2.5D visualizations, and 3D visualizations. Each method caters to distinct aspects of ontology visualization, from simple indented lists that show hierarchical relationships in a straightforward, text-based format to more complex 3D visualizations that provide a spatial representation of data but may struggle with the translation to 2D screens. Additional features enhancing these visualizations include radar views for a minimap perspective, graphical and semantic zooming to adjust detail, entity focus to highlight specific data points, and history tracking for navigation. Advanced techniques like concept clustering and semantic zooming allow for dynamic interaction with the ontology, emphasizing the visualization's adaptability to user needs and the complexity of the information displayed. Ultimately, visualization tools for ontologies serve two primary purposes: they can display data records structured according to the ontologies, or they can visualize the semantic constructs in OWL and RDFs that form the foundation of the ontologies themselves. The latter category of tools is crucial for illustrating how ontologies are built, revealing the composition and interactions of various semantic elements that enable machines to comprehend and process the meaning of information and data, and infer new data.

Regarding specialized visualization tools designed for displaying OWL and RDFS constructs using 'signs' or 'symbols', two notable examples are Chowlk (Chávez-Feria et al., 2022) and WebVOWL (Lohmann et al., 2017). Chowlk [2] enables users to edit ontologies through a visualization interface, making it an invaluable resource for those needing to develop or modify ontologies while assessing their

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[2] Chowlk is accessible at: https://chowlk.linkeddata.es/notation.html

structure and semantics. Conversely, WebVOWL [3] focuses exclusively on inspection, offering a platform for users to examine and understand the relationships and structures within an ontology, though it lacks editing capabilities. Despite their significant contributions to enhancing the accessibility and usability of ontological data, these tools also face specific limitations. Chowlk, for example, does not permit the uploading and visualization of existing ontologies, limiting its applicability. Meanwhile, WebVOWL, while providing a visual insight into ontology semantics, falls short in effectively revealing the detailed logical structure of ontologies, which can hinder a thorough analysis of their construction. Moreover, both tools do not support the visualization of all RDFs and OWL constructs.

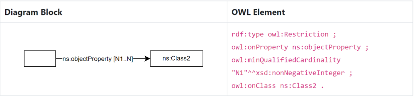

Diagram Block	OWL Element
ns:objectProperty [N1..N] ns:Class2	rdf:type owl:Restriction ; owl:onProperty ns:objectProperty ; owl:minQualifiedCardinality "N1"^^xsd:nonNegativeInteger ; owl:onClass ns:Class2 .

Figure 1: Example visualization for the semantic OWL construct (owl:minQualifiedCardinality) adopted by Chowlk. The image has been sourced from https://chowlk.linkeddata.es/notation.html.

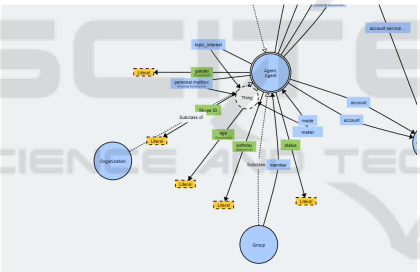

Figure 2: Example visualization for semantics OWL and RDFs constructs adopted by WebVOWL. The image has been sourced from https://service.tib.eu/webvowl/.

The lack of visualization tools capable of allowing users to fully visually inspect the axiomatic and taxonomic structures of vocabularies poses a significant challenge. This problem is compounded by the absence of a standardized method for visually representing OWL and RDFs constructs. Such limitations create a substantial barrier for those working to develop, refine, or simply understand the intricate relationships and rules within these semantic frameworks. The ability to visually navigate these structures is crucial for effective analysis and verification of ontological consistency, which underpins many advanced data processing and AI systems. Moreover, the gaps in visualization capabilities are particularly problematic in light of the limitations of open-source reasoners, as it will be further explained in the subsequent section.

3 REASONERS' LIMITS

Reasoners are powerful tools used in the semantic web to process and infer logical consequences from a set of ontologies. Inference is the process by which these tools deduce new knowledge from the facts already defined in the ontology. For example, if an ontology states that all mammals are warm-blooded and that whales are mammals, a reasoner can infer that whales are warm-blooded. This ability to derive new facts extends the utility of ontologies, enabling more complex queries and enhanced data interaction.

Contradictions occur when conflicting information is deduced or entered into the ontology, such as stating both that no birds are mammals and that some birds are mammals. Effective reasoners are designed to detect these contradictions, which are critical for maintaining the integrity and reliability of data. However, detecting contradictions does not always happen automatically. In complex ontologies where multiple relationships and properties interact in subtle ways, contradictions might be less apparent and can be overlooked by reasoners, especially if the reasoner is not fully compliant with all rules and nuances of the ontology language or is limited by performance constraints.

According to Gomez-Perez et al. (Gomez-Perez, 1994), (Gomez-Perez et al., 2001), (Gomez-Perez et al., 1999) and Fahad et al. (Fahad et al., 2007), (Fahad and Qadir, na), inconsistencies and contradictions in ontologies typically arise from three main types of errors: Circluatory Errors, Partition Errors and Semantic Inconsistency Errors. Circulatory Errors occur when a class or property is wrongly defined as a subclass or superclass (or subproperty, superproperty) of itself, creating a loop in the ontology's hierarchy. Partition Errors happen when an entity, such as a class, property, or instance, is incorrectly classified under multiple disjoint categories, often during the process of breaking down a concept into subconcepts or when dealing with exhaustive decomposition where an external instance does not fit any defined category. Lastly, Semantic Inconsistency Errors arise from incorrect hierarchical classifications, such as placing a concept as a subclass under an incompatible superclass. This type of error usually stems from three situations: subclasses representing a broader domain than their superclass (i.e. weaker domain specified by subclass error), subclasses introducing characteristics that contradict their superclass's traits (i.e.

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[3] accessible at: https://github.com/VisualDataWeb/WebVOWL

domain breach specified by subclass error), and subclasses being placed under a concept from a disjoint domain (i.e disjoint domain specified by subclass error).

In 2008, Fahad et al (Fahad et al., 2008). conducted a test which revealed that a number of reasoners were unable to detect partition errors and semantic inconsistency errors. Recently, I replicated this exact experiment using a selection of well-regarded reasoners to assess their current capabilities. Among these were HermiT 1.4.3.456, known for its strict adherence to OWL 2 DL ontologies, and Pellet 2.2, still relevant for its extensive OWL 2 DL support. I also tested Pellet Incremental to evaluate its efficacy in dynamic environments where ontologies frequently change, allowing for real-time updates without the need for full reprocessing. Additionally, Elk, valued for its speed in handling EL++ ontologies despite potential stability issues, and FaCT++, recognized for its performance albeit with installation challenges, were included in the test. The ontology used was the same as described by Fahad et al.(Fahad et al., 2008), and the reasoners were operated within the Protege framework. The following results were attained.

In the experiment replicating the tests originally performed by Fahad et al.(Fahad et al., 2008), I found that the current selection of reasoners still struggled with detecting specific types of semantic inconsistency errors. Notably, they failed to identify issues such as weaker domain specified by subclass error. For example, an error was not detected in a scenario where ’Owner owns some PassengerVehicle’ was created as a subclass of the concept ’Owner4Vehicle owns exactly 4 PassengerVehicle’. Additionally, the Domain Breach Specified by Subclass Error went undetected, such as in the case where ’OwnerManyVehicle’, defined as owning more than 3 but less than 8 PassengerVehicles, was incorrectly subclassed under ’Owner of exactly 4 Vehicles’.

Moreover, the reasoners did not detect violations of the OWL propertyDisjointWith vocabulary term, which specifies that two properties should never relate the same pair of resources. Instances where properties supposedly disjoint still related the same entities were overlooked by reasoners.

The experiment also revealed shortcomings in the reasoners’ ability to infer new information based on conceptual distances or hierarchies extending beyond an arc distance of +10 from the initial concept. Furthermore, Circulatory Errors, which lead to circular reasoning and thus inconsistencies, were not recognized by the reasoners. These results highlight persistent gaps in the capabilities of ontology reasoners, underscoring the need for ongoing improvements in their algorithms to handle complex logical constructs more effectively. Ultimately, these findings emphasize that reasoners cannot solely be relied upon by ontology engineers during the conceptualization process or when assessing the consistency and efficiency of their models. This underscores the necessity for additional tools to aid in the development and verification of ontologies. Visualization tools, in particular, can offer substantial support in this regard, provided there is a standardized and uniform way used to visually represent and refer to OWL and RDFS constructs. By integrating such visualization tools, ontology engineers can gain better insights into the structure and interrelations within their ontologies, making it easier to spot inconsistencies and inefficiencies that reasoners might miss. This dual approach of using both reasoners and visualization tools can significantly enhance the robustness and utility of semantic data modeling.

Building on the identified limitations of ontology reasoners and the potential of visualization tools to enhance the conceptualization and validation process in semantic data modeling, it becomes apparent that integrating semiotics (i.e. the study of signs and symbols and their use or interpretation) into ontology engineering could provide further advantages. Just as reasoners parse and interpret data based on logical constructs, visualization tools can use semiotic principles to encode and represent complex information, making abstract concepts more accessible and interpretable as it will be discussed in the next part.

4 THE SEMIOTICS OF VISUALIZATION TOOLS

Semiotics, the study of signs and symbols and their interpretation, serves as the foundational framework of semantics, crucial for building the semantic web. Signs encompass a variety of forms including words, images, objects, and even smells, which acquire meaning only when humans assign significance to them. This field is heavily influenced by the theories of Ferdinand de Saussure and Charles Sanders Peirce, as highlighted by Vickers et al. (Vickers et al., 2013). Saussure’s model explains a sign as consisting of a signifier (the form the sign takes, such as a word or sound) and the signified (the concept it represents). For example, the sound pattern /cat/ signifies the animal cat. Conversely, Peirce’s model introduces a triadic relationship involving the object (the entity being represented), the representamen (the physical form of the sign), and the interpretant (the understanding attributed to the sign by observers).

Applying these principles to ontology visualization allows for the use of diverse signs to effectively demonstrate how different ontologies are structured, thereby enabling various types of structural analyses. Each sign or symbol in a visualization could be deliberately designed to represent specific OWL and RDFS vocabulary terms. This method not only standardizes visual representations but also assigns specific, agreed-upon meanings to these signs. For example, different shapes, colors, or icons might be used to denote classes, properties, subclasses, and other ontological elements, transforming a visual diagram into a readable, meaningful map of an ontology.

This semiotic encoding bridges the gap between the complex data managed by reasoners and the human understanding necessary for efficient ontology engineering. It allows engineers to quickly grasp the ontology's structure and logic, facilitating the identification of relationships, hierarchies, and potential inconsistencies without needing to parse complex codes or logical expressions. Ultimately, integrating the computational power of reasoners with the intuitive clarity of semiotically-enhanced visualization tools enables ontology engineers to achieve a deeper, more nuanced understanding of their data models.

The creation of a tool designed to visualize standardized symbols representing vocabulary terms of OWL and RDFS would bring significant benefits to the field of ontology engineering. Such a tool would greatly enhance the clarity and accessibility of complex ontological structures, making it easier for engineers and stakeholders to grasp and interact with the semantic layers underlying their data. Standardized visual representations would facilitate quicker and more accurate interpretation of relationships and hierarchies within ontologies, reducing the cognitive load on users and speeding up both the design and troubleshooting processes. Additionally, by providing a universal language of visual symbols, this tool would promote better communication and collaboration across diverse teams and disciplines, ensuring that ontologies are not only consistently understood but also more effectively integrated into broader systems. This could lead to advancements in data interoperability and more seamless integration of semantic web technologies across different platforms and applications, ultimately driving innovation and efficiency in the use and management of knowledge.

5 CONCLUSION

The integration of semiotic principles into ontology visualization tools is not merely an enhancement but a necessity. As the Semantic Web continues to grow in both size and significance, the ability to effectively visualize ontological structures in a semantically meaningful way becomes critical. Tools that can bridge the gap between complex semantic structures and user-friendly visual representations will play a pivotal role in the advancement of knowledge engineering. This endeavor not only supports the technical development of ontologies but also facilitates a broader understanding and adoption of semantic technologies across various sectors.

In this evolving landscape, the development and standardization of visualization tools capable of accurately representing OWL and RDFs constructs are paramount. By creating systems that visually encode ontology semantics, we enable more intuitive interactions with data, enhance the capacity for insight, and significantly improve the accuracy of ontology engineering tasks. This approach not only aids ontology engineers in managing the inherent complexities of semantic frameworks but also empowers stakeholders across different domains to engage with and leverage the full potential of semantic technologies.

Moreover, these visualization tools serve as a critical complement to reasoners, addressing the current limitations in detecting inconsistencies and inferring new knowledge. By integrating robust visualization technologies with advanced reasoning capabilities, we can forge a more comprehensive toolkit for ontology engineers, enhancing both the development and application of ontologies within the digital ecosystems.

Thus, as the advocacy for the advancement of semantic web technologies continues, the focus must also shift towards refining the tools that facilitate this advancement. Establishing a standard for visual representations of semantic data, paired with ongoing enhancements to reasoning technologies and visualization tools, will not only address the current challenges but also pave the way for future innovations in this critical area of technology.

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REFERENCES

Bernasconi, E., Ceriani, M., Di Pierro, D., Ferilli, S., and Redavid, D. (2023). Linked data interfaces: A survey. *Information*, 14(9):483.

Chávez-Feria, S., García-Castro, R., and Poveda-Villalón, M. (2022). Chowlk: From uml-based ontology conceptualizations to owl. In *Proceedings of the 19th Extended Semantic Web Conference (ESWC 2022)*, page Conference specific pagination. Accessed: 2024-04-18.

Commission, E. (2022). Moving towards a european data space: New eu law for data-sharing. https://data.europa.eu/en/news-events/news/moving-towards-european-data-space-new-eu-law-data-sharing. Last accessed 2024/04/18.

Corcho, O. and Simper, E. (2022). data.europa.eu and the european common data spaces, a report on challenges and opportunitie.

Dudás, M., Lohmann, S., Svátek, V., and Pavlov, D. (2018). Ontology visualization methods and tools: A survey of the state of the art. *The Knowledge Engineering Review*, 33.

Fahad, M., Qadir, M., and Noshairwan, W. (2007). Semantic inconsistency errors in ontologies. In *Proceedings of the IEEE GRC 2007*, pages 283–286, Silicon Valley, USA. IEEE Computer Society.

Fahad, M. and Qadir, M. A. (n.a). A framework for ontology evaluation. In *Proceedings of the Workshop at CEUR Workshop Proceedings*, Mohammad Ali Jinnah University, Islamabad, Pakistan. CEUR Workshop Proceedings.

Fahad, M., Qadir, M. A., and Shah, S. (2008). Evaluation of ontologies and dl reasoners. In *Intelligent Information Processing IV*, volume 288, pages 17–27. Springer.

Gomez-Perez, A. (1994). Some ideas and examples to evaluate ontologies. Technical report, Knowledge Systems Laboratory, Stanford University, Stanford, CA.

Gomez-Perez, A. et al. (1999). Evaluation of taxonomic knowledge on ontologies and knowledge-based systems. In *Proceedings of the International Workshop on Knowledge Acquisition, Modeling and Management*.

Gomez-Perez, A., Lopez, M., and Garcia, O. (2001). *Ontological Engineering: With Examples from the Areas of Knowledge Management, E-Commerce and the Semantic Web*. Springer.

Lohmann, S., Haag, F., Ertl, T., and Negru, S. (2017). Visualizing ontologies with vowl. *Semantic Web Journal*. Accessed: 2024-04-18.

Skulmowski, A. and Xu, K. M. (2022). Understanding cognitive load in digital and online learning: A new perspective on extraneous cognitive load. *Educational Psychology Review*, 34:171–196.

Vickers, P. et al. (2013). Understanding visualization: A formal approach using category theory and semiotics. *IEEE Transactions on Visualization and Computer Graphics*.