Getting formal Ontologies closer to final users through Knowledge Graph Visualization: interpretation and misinterpretation

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Abstract. Knowledge Graphs are extensively adopted in a variety of disciplines to support knowledge integration, visualization, unification, analysis and sharing at different levels. On the other side, Ontology has gained a significant popularity within machine-processable environments, where it is extensively used to formally define knowledge structures. Additionally, the progressive development of the Semantic Web has further contributed to a consolidation at a conceptual level and to the consequent standardisation of languages as part of the Web technology. This work focuses on customizable visualization/interaction, looking at Knowledge Graphs resulting from formal ontologies. While the proposed approach in itself is considered to be scalable via customization, the current implementation of the research prototype assumes detailed visualizations for relatively small data sets with a progressive detail decreasing when the amount of information increases. Finally, issues related to possible misinterpretations of ontology-based knowledge graphs from a final user perspective are briefly discussed.

Keywords: Ontology · Knowledge Graph · Data Visualization · Uncertainty

1 Introduction

Knowledge Graph (or Semantic Network) has recently gained popularity in a variety of contexts and disciplines where it is ubiquitously used without a commonly accepted well-established definition [9]. An effective use of Knowledge Graphs is considered to be critical as it provides structured data and factual knowledge in scope [23].

In the more specific field of knowledge representation and reasoning [7], a knowledge graph is understood as a graph-structured representation of a given knowledge base composed of interrelated entities and associated semantics. It is considered an effective framework for knowledge integration, visualization, unification, analysis and sharing at different levels. Knowledge graph relevance is evident in literature as it is widely adopted in the context of different disciplines

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and applications (e.g. reccommendation systems [35] or education [6]) along a number of issues and challenges, such as, among others, identification [31], embedding [34], refinement [24], construction [19] and learning [18]. On the other side, Ontology has gained a significant popularity within machine-processable environments [14], where it is extensively used to formally define knowledge structures. Additionally, the progressive development of the Semantic Web [4] has further contributed to a consolidation at a conceptual level and to the consequent standardisation of languages (e.g. RDF/RDFS [22], OWL [1], SPARQL [2]) as part of the Web technology. Knowledge graphs are not necessarily specified by using formal standard languages. However, it becomes a compelling need wherever the target knowledge is dynamically understood as part of interoperable and re-usable environments. Additionally, ontological structures are a de facto requirement in many practical cases (e.g. [8][5]).

This work focuses on customizable visualization/interaction, looking at Knowledge Graphs resulting from formal ontologies. As concisely discussed later on in the paper, the most common approaches for visualization work manly at an ontology level, focusing on the ontology schema. That is normally considered to be effective to meet the needs of ontology developers and, more in general, to overview the knowledge structure. However, Ontology and Knowledge Graph are in general two well different concepts as the former is commonly understood as a formal specification of the knowledge space, while the latter is a representation as a graph of the same knowledge space that should meet visualization requirements from a final user perspective. In other words, ontology works mostly on the machine side and Knowledge Graph provides a domain or application specific interface for final users. Therefore, there is a practical gap between Ontology and Knowledge Graph visualization that quite often forces an ad-hoc approach. This work aims to reduce such a gap through a standard, yet customizable, strategy that presents ontologies as application-level Knowledge Graphs. It ultimately wants to get a given knowledge space as close to final users as possible. Additionally, interaction capabilities are empowered by a smooth integration within the visualization environment of formal query and informal search functionalities. While the proposed approach in itself is considered to be scalable via customization, the current implementation of the research prototype assumes detailed visualizations for relatively small data sets with a progressive detail decreasing when the amount of information increases.

The paper follows with a related work section, which concisely addresses ontology visualization. The approach provided and the implementation of the current prototype is proposed later on, while Section 4 discusses the interpretation of ontology-based knowledge graphs from a final user perspective. As usual, the paper ends by summarising the contribution looking at possible future work.

2 Related Work

Ontology visualization methods and tools have been extensively discussed in the recent past [15]. Major difficulties are related to the descriptive nature of ontolo-

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gies, which normally provide vocabularies to dynamically build knowledge according to a non-prescriptive approach. Moreover, ontologies are normally specified by using rich data models. In the specific case of Web ontologies developed upon OWL, we can distinguish at least three different conceptual sub-sets: the TBox is normally associated with the ontology schema (concepts/classes and relationships), the ABox is commonly related to instances of concepts and, finally the RBox includes inference rules and relational axioms. In addition, metadata can be associated with entities (e.g. through annotation properties in OWL).

An exhaustive overview of those solutions is out of the scope of this paper. However, looking at the different techniques, two main class of solution can be identified as follows:

– *Indented list.* It is a very popular method among developers and, therefore, within ontology editors. For instance, Protege [11], which is the most famous ontology editor by far, adopts such a technique to provide simple and effective browsing of the different components, i.e. classes, properties and individuals ((example in fig.1). While such an approach can be useful also to final users in a variety of possible applications and situation, it is in principle designed for ontology developers and it is not suitable as a primary technique to interact with knowledge graphs. The most common approach is currently to integrate indented list with other visualization techniques (e.g. through plug-ins in Protege [33]).

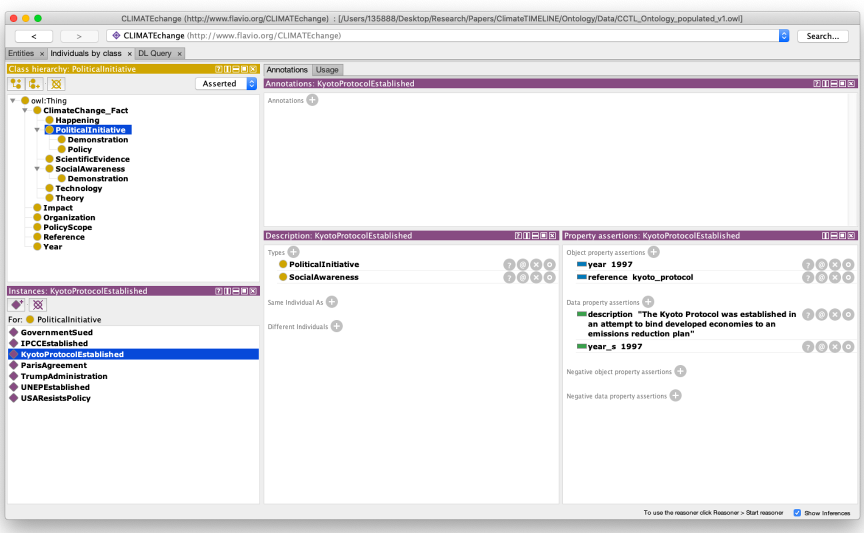

Fig. 1. Visualization of Climate Change TimeLine Ontology [30] in Protege.

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- *Graph-based visualization.* Methods based on graph visualization [16] are considered to be quite effective and are, therefore, extensively used in a number of different contexts. An interesting comparison of available tools from a practical perspective is proposed in [12]. A well-known visualization tool is VOWL [20] which, like most tools, focuses mainly on the ontology schema to provide an overview of the ontology structure. Populated ontologies are more rarely addressed (e.g. [3]).

The solution proposed in the paper aims to a flexible and customizable visualization of knowledge graphs underpinned by formal ontologies.

3 Ontology-Based Knowledge Graph Visualizer (OB-KGV)

This section aims to provide an overview of the tool developed from a final user perspective. *Ontology-Based Knowledge Graph Visualizer (OB-KGV)* is developed in Java upon the reasoning capabilities provided by PELLET [32] and its query wrapper. Therefore, the tool takes in input an OWL ontology and produce a post-reasoning visualization within a customizable environment to adapt to the different characteristics of the considered data structures as well as to the intent and the extent of the visualization at an application level.

The approach proposed is considered to be scalable via customization and the priority is currently on usability, according to the Technology Acceptance Model [17] and looking at users with a minimum yet existing background in ontology-related fields. Some simplifications and terminology refinement could further increase the user base.

In the next sub-sections, the main features of the tools are discussed by firstly addressing a generic visualization mode, then looking more specifically at the provided views and, finally, at the interaction capabilities.

3.1 Visualization of semantic structures

An example of visualization by adopting the most comprehensive available view - i.e. the *ontology view* - is shown in fig. 2. This is a small dataset defined according to the virtual table model [29] which allows to systematically represent a common dataset in a relational table as an OWL structure.

Such a representation considers all OWL entities, including class, object and data properties and instances. Annotation properties can be accessed though the query/search interface but are not visualised as part of the Knowledge Graph in the current prototype to avoid a further increase of the density for the main knowledge structure. It means that basically entities and relationships of any kind can potentially be considered in the visualization. Such a generic view can be customised in terms of entity filtering, clustering, labelling and visualization area/style.

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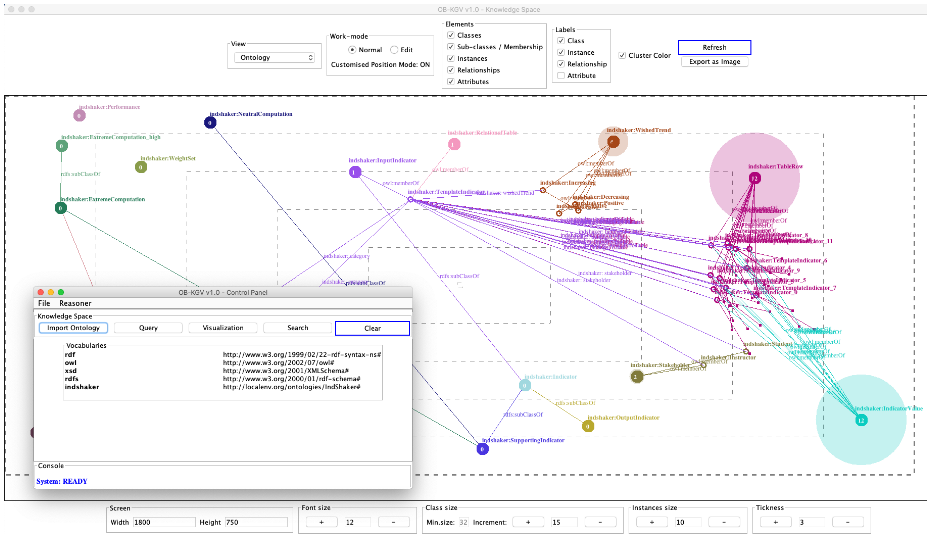

Fig. 2. Visualization of a small ontology.

3.2 Customized views

In addition, three different pre-defined yet customizable views are provided by the tool:

- *Schema view.* It aims to overview the ontology schema and, therefore, the knowledge structure according to a classic visualization approach enriched in this specific case by the information on the cluster size (namely the number of instances belonging to a given class). Such a view considers OWL classes and the relationships existing among them. It is built by processing the sub-class, domain and range OWL relational axioms. Therefore, it is effective only when such structures are effectively used in the considered ontologies.
- *Data view.* It implements in a way the opposite philosophy by focusing on data - i.e. the ontology population - by considering the instances of classes (but not classes) and the relationships existing among such instances. Also attributes can be considered in order to provide an effective understanding of the available data.
- *Knowledge Graph view.* It can be considered a middle term between the two previous views as it focuses on classes and instances and relationships existing among them avoiding data details (attributes). It is by definition a balanced view which is considered to be suitable in a wide range of cases.

The Climate Change TimeLine [30] is an ontology that organizes Climate Change-related information according to a time-line structure. Such an ontology is visualized according to the different views in fig. 3 and 4.

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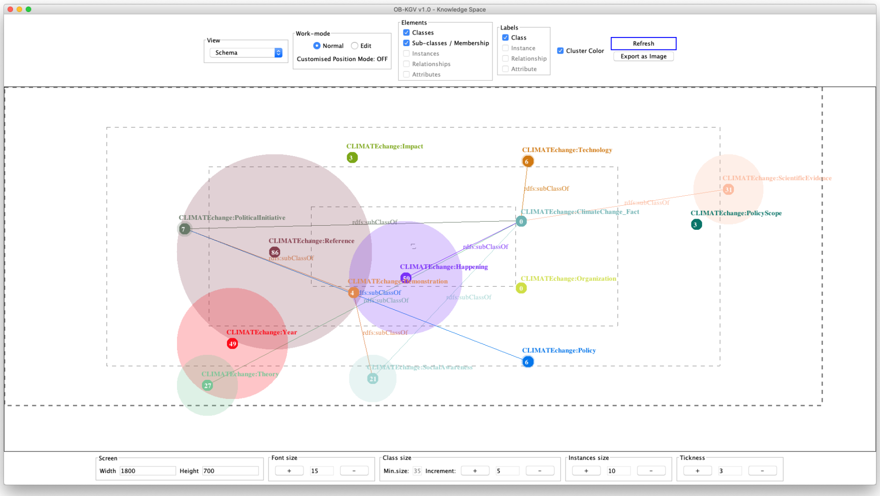

Fig. 3. Schema view.

3.3 Query and Search

The current research prototype enables the interaction with the knowledge structure by providing two integrated mechanisms:

- *Searching (natural language).* The searching tool allows users to browse the semantic network by providing keywords that are matched with available ontological entities like in common search engines. Results are provided as a list, as well as the interested components are highlighted in the graph. While the former mechanism is critical to identify formal concepts in big or dense graphs, the latter provides a visual representation of the result set. This interaction mode is potentially suitable to any user, including also user without any background in ontology-related fields.
- *Formal Query (SPARQL).* The query interface supports formal query in SPARQL [2]. Such an approach enables the power and the complexity of SPARQL [25] but it is evidently suitable only to users with specific technical skills in the field.

The two interfaces previously described are designed to work as part of an integrated framework. An example is reported in fig. 5: first, the search interface is used to search the keyword "theory" within the Climate Change TimeLine ontology (fig. 5(a); then, the formal concept identified ("CLIMATEchange:Theory") is adopted to retrieve the associated cluster by formal query (fig. 5(b)).

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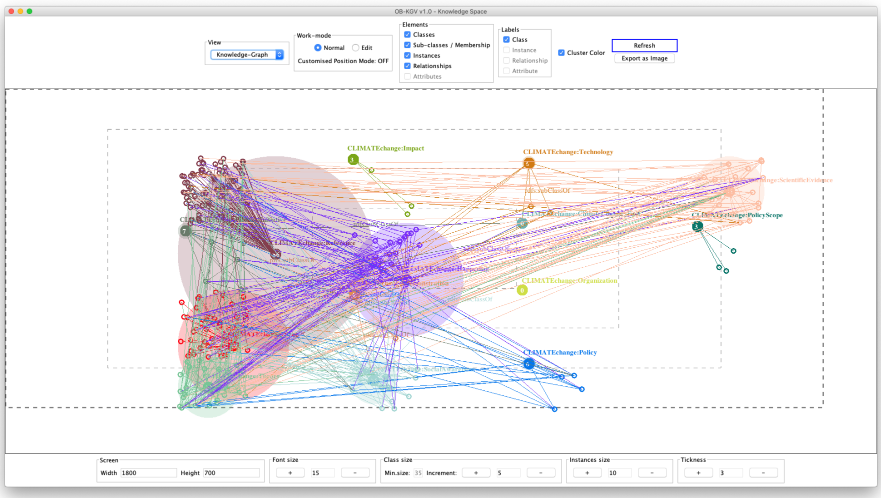
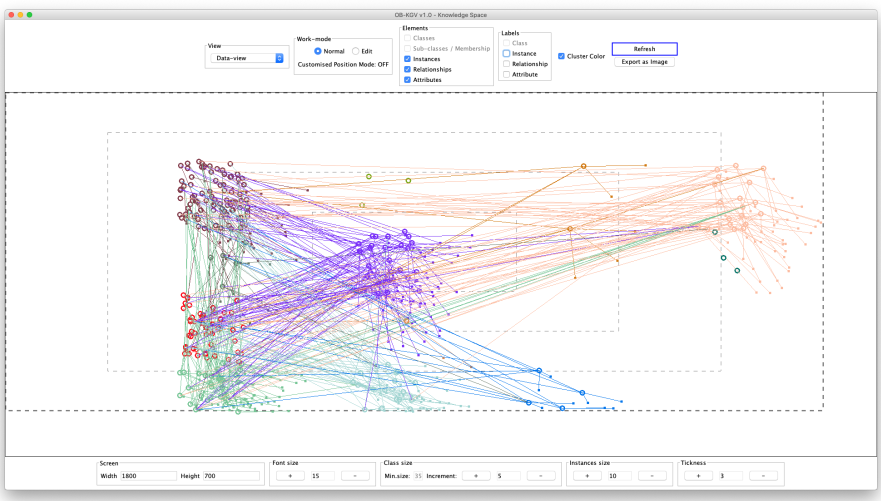


(a) Knowledge Graph view.



(b) Data view.

Fig. 4. Knowledge Graph vs Data view.

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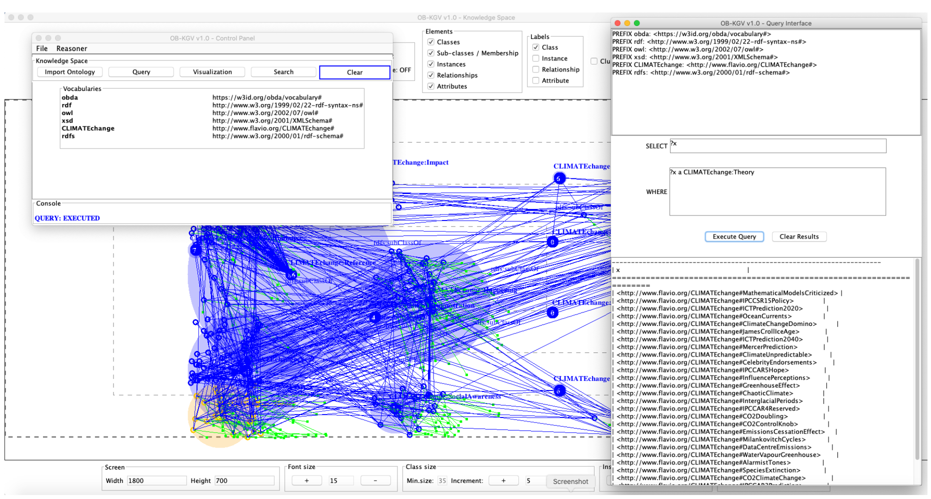
(a) Search on the semantic structure.



(b) Formal query (SPARQL) on the semantic structure.

Fig. 5. An example of interaction by using the searching and query interfaces.

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4 Ontology-based Knowledge Graph interpretation: a user perspective

Formal ontologies in computer systems implies a certain complexity as an attempt to represent human knowledge within a machine World. Even the formalization of a very simple domain (e.g. [26]) relies on the contextual understanding of the information. Such a complexity is normally function of the adopted data model capability and may increase significantly when advanced features are adopted (e.g. [27]).

By adopting Ontology-based Knowledge Graphs, final users are expected to directly interact with the knowledge space with a proper level of abstraction. That is normally enabled by automatic reasoners that provide a user level knowledge infrastructure by computing inference rules in the background of the system. While at a theoretical level the resulting knowledge space represented as a graph is supposed to be a reasonable interface for final users, there are a number of practical aspects to be considered.

Indeed, more than one factor may impact an effective interaction with the knowledge space. The usability of tools [21] and of underlying ontologies [10] definitely play a critical role, although the understanding of "quality" could be in some case domain or application-specific. From a user perspective, the risk of misinterpretation of the knowledge space [13] can be addressed according to two different dimensions: the expertise in a given domain and the technical skills. These dimensions are briefly discussed in the following sub-sections.

4.1 Expertise in the domain

In general terms, from a domain knowledge point of view, three different classes of final users may be defined as follows:

- *Internal User*. By having a full knowledge and unambiguous understanding of the vocabulary adopted - i.e. the underlying ontology - it is the ideal user, regardless of technical skills.
- *Expert User*. As an expert in the target domain, such a kind of user is supposed to be able to correctly understand conceptualizations. It differs from the previous because has no knowledge of the specific ontology adopted but it is expected to have the background to understand it at an application level.
- *Generic User*. This is a user without a specific expertise in the considered domain.

For internal users the risk of misinterpretation of the target knowledge is in theory very low, if not negligible. As per definition, a detailed knowledge of the vocabulary is a guarantee of correct interpretation of concepts and, therefore, of associated data. Additionally, the comprehensive understanding of the vocabulary facilitates an holistic view as well as more specific and fine-grained, yet contextual, analysis.

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An expert user as previously described is expected to be by far the most common user. That is the typical case of a professional or a researcher in a given domain who is using a third-party ontology-based tool. Ontology-based Knowledge Graph should be a suitable asset as long as proper annotations are associated to main concepts and entities. Such a metadata normally contributes to fill the gap between domain knowledge and concrete implementations. However, due to the intrinsic complexity of certain domains (e.g. [28]), an unified view is not always easy to achieve and requires a detailed knowledge of the adopted vocabulary.

A generic user could take advantage of KGs, which are expected to enable in fact the interaction with the knowledge space. However, the lack of specific knowledge in the domain increases significantly the risk of misinterpretation.

4.2 Technical skills

Looking at a user classification from a more technical perspective, we can reasonable define the following categories:

- *Ontology-specific background*. A user with a specific ontology background is supposed to fully understand and have a concrete expertise in the technology adopted (e.g. able to use formal query languages).
- *Technical background*. User with a significant technical background other than ontology-specific. It could be a data analyst for instance.
- *Non-technical user*. Users without a clear technical background.

An ontology-specific background allows a direct and effective interaction with the knowledge space by using formal query languages without brokers. That is evidently the ideal situation which is, however, unrealistic in most cases. A technical background as previously described includes a wide range of possible users and doesn't necessarily guarantee effective interaction. However, a technical background could allow an understanding of metrics for graph analysis and could facilitate a relatively good quality of experience. A non-technical user mainly relies on abstraction mechanisms at different levels (e.g. interfaces based on a natural language) which could be application-specific.

Generally speaking, the ability to properly interact with the knowledge space reduces the risk of misinterpretation.

5 Conclusions and Future Work

OB-KGV aims at an exhaustive and highly customizable solution for the visualization of knowledge graphs specified as formal OWL ontologies. Developed in Java upon PELLET [32], the research prototype provides an interactive post-reasoning visualization environment in which final users can browse the knowledge structure by adopting both formal query and natural language.

The approach proposed is considered to be scalable via customization. However, the current implementation of the research prototype assumes detailed

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visualizations for relatively small data sets with a progressive detail decreasing when the amount of information increases. Such a prototype is also supposed to evolve in the next future to incorporate functionalities aimed at improving the user experience as well as to integrate advanced functionalities in terms of graph analysis, data integration and learning.

The most evident limitation is the current lack of user validation that could be object of future work.

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