

A Visual Notation for the Integrated Representation of OWL Ontologies

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Abstract: The paper presents a visual notation for the Web Ontology Language (OWL) providing an integrated view on the classes and individuals of ontologies. The classes are displayed as circles, with the size of each circle representing its connectivity in the ontology. The individuals are represented as sections in the circles so that it is immediately clear from the visualization how many individuals the classes contain. The notation can be used to visualize the property relations of either the classes (conceptual layer) or of selected individuals (integrated layer), while certain elements are always shown for a better understanding. It requires only a small number of graphical elements and the resulting visualizations are comparatively compact. Yet, the notation is comprehensive, as it defines graphical representations for all OWL elements that can be reasonably visualized. The applicability of the notation is illustrated by the example of the Friend of a Friend (FOAF) ontology.

1 INTRODUCTION

The Web of Data has attracted large interest for both data publishers and consumers in the last years. Several organizations have begun publishing their data in RDF (Resource Description Framework)¹ and linking it with other data, leading to a significant growth in RDF triples available on the Web of Data (Bizer et al., 2009). As (Dadzie and Rowe, 2011) point out “making sense of such data presents a huge challenge to the research community”. User-centered visualizations are considered essential to help people understanding the data.

Ontologies play a key role in this context. An ontology is defined as “a set of knowledge terms, including the vocabulary, the semantic interconnections and some simple rules of inference and logic, for some particular topic” (Hendler, 2001). The primary purpose of an ontology is to classify things in terms of semantics for a specific domain. Ontologies provide the backbone for publishing RDF data in a semantically meaningful way. Especially the Web Ontology Language (OWL)² is widely used to define the conceptual schema, the classes, individuals, and the relationships between them. However, OWL is mainly designed for use by applications in order to support interoperable data exchange, machine processing, and

reasoning. Even though it provides great means to describe and integrate information on the Web, its text-based representation is difficult to understand for average users.

While the World Wide Web Consortium (W3C)³ provides a notation for the visualization of RDF graphs⁴, it does not provide a notation for OWL. Since any OWL ontology can be represented as RDF graph, it can also be visualized using the RDF notation. However, as every single RDF statement is separately visualized, this can result in very large visualizations with plenty of nodes and edges. Such RDF visualizations of OWL ontologies are not only hard to read but they also fail to adequately reflect the OWL semantics, as the OWL constructs are split up into multiple RDF triples.

Therefore, research has addressed the issue of providing visualizations for OWL ontologies. However, most of the existing approaches represent classes and individuals in a mutually exclusive manner, without providing an integrated view. Moreover, different graphical representations are used to depict the classes, individuals, properties, and their relationships. An integrated view on ontologies that uses a uniform graphical representation can therefore be regarded as crucial for a better understanding of ontologies and linked data.

¹<http://www.w3.org/RDF/>

²<http://www.w3.org/2004/OWL/>

³<http://www.w3.org>

⁴<http://www.w3.org/RDF/Validator/>

In order to fill this gap, this paper presents a visual notation for OWL ontologies that represents both classes and individuals in a comprehensive yet compact manner. A central goal is to provide both expert and non-expert users with an easy-to-understand notation optimized for OWL ontologies. The key idea of the approach is to offer an integrated view on ontologies, where classes are represented as differently sized circles that are shown along with the individuals they contain.

In the following, we first summarize related work in Section 2. In Section 3, we present the developed visual notation for OWL ontologies. In Section 4, we illustrate the applicability of the notation by the example of the Friend of a Friend (FOAF) ontology. The paper ends with a conclusion and an outlook on future work in Section 5.

2 RELATED WORK

Several approaches for the visual representation of ontologies and linked data have been presented in the last years (Guo and Chan, 2011; Dadzie and Rowe, 2011; Katifori et al., 2007; Geroimenko and Chen, 2006). Most of them are based on a two-dimensional plane, though some propose to use 3D representations. Little surprising, most users “seem to dislike chaotic and too cluttered overviews” but “tend to prefer visualizations that offer the possibility of an orderly and clear browsing of the presented information” (Katifori et al., 2007). Finding a good balance between comprehensiveness and ease-of-use is one of the key challenges. Therefore, many works show either only a part of the ontology or end up with very complex representations.

A number of visualization approaches have been implemented as plugins for ontology editors like Protégé⁵. Some of them (e.g. OWLViz⁶) simply visualize the class hierarchies of ontologies, while others (e.g. OntoGraf⁷), allow for more comprehensive visualizations that include a representation of individuals and different property relations. Yet, no clear distinction between property types or between classes and individuals is made in the graphical representation of OntoGraf. The notation rather relies on colors and abstract symbols to indicate different node and link types.

A more complete OWL visualization is provided by GrOWL (Krivov et al., 2007), a graphical editor for

OWL ontologies. It has been particularly designed for the sublanguage OWL DL and the semantics of Description Logic (DL), for instance, by offering separate visualizations for the TBox, ABox, and RBox of an ontology (Rudolph, 2011). However, the graphical representation quickly becomes complex and large in size, as every individual is defined in a separate node.

Work has also been done in the direction of representing ontologies as UML class diagrams⁸, mostly by defining mappings between elements from OWL and UML (Cranefield, 2001). The Object Management Group (OMG) formally specified such mappings in the Ontology Definition Metamodel (ODM)⁹. One implementation in this context is OWL-GrEd (Barzdins et al., 2010), a graphical OWL editor that uses UML elements for the representation of ontologies. A disadvantage of these approaches is again their limited visual scalability, especially when it comes to the representation of a large number of individuals.

Other approaches focus on more specific visualization tasks. For instance, the RelFinder (Heim et al., 2010) visualizes relationships between individuals in ontologies and makes these relationships interactively explorable. It nicely depicts a limited set of instance data and helps to discover commonalities, but it does not provide a global picture of the ontology.

OntoTrix (Bach et al., 2011) presents a hybrid network visualization technique that uses both node-link diagrams and adjacency matrices to represent parts of the ontology. Though an interesting combination of visualization techniques, it relies on the users’ capabilities to correctly interpret the matrix representations and the used color-coding, which can be problematic at least for average users.

Finally, there are also visualization approaches that represent the classes and individuals in ontologies as differently sized circles. One such work is CropCircles (Wang and Parsia, 2006), which visualizes the OWL class hierarchy using nested circles. The size of the circles is proportional to the position of the classes in the hierarchy. OOBIAN Insight¹⁰ also makes use of nested circles to visualize ontology-based data. Like in GrOWL, the visualization quickly becomes complex and large in size, making it hard to read. Another example of visualizing ontologies with nested circles is the DOPE Browser presented in (Stuckenschmidt et al., 2004), where individuals are grouped into circle-shaped class representations and linked together to form a cluster map.

The review of related work showed that most ex-

⁵<http://protege.stanford.edu>

⁶<http://protegewiki.stanford.edu/wiki/OWLViz>

⁷<http://protegewiki.stanford.edu/wiki/OntoGraf>

⁸<http://www.uml.org>

⁹<http://www.omg.org/spec/ODM/>

¹⁰<http://dbpedia.oobian.com>

isting approaches focus on the terminological part of ontologies (i.e. the classes and their relationships), while little emphasis is placed on the individuals belonging to the classes (i.e. the actual data). Furthermore, many of the proposed visualizations do not provide an explicit description of the visual notation, i.e. a specification that clearly defines the semantics of the graphical elements.

In order to overcome these limitations, we developed a visual representation that allows for an integrated view on the TBox and ABox of ontologies. Furthermore, all mappings between the graphical representations of our notation and OWL elements are clearly specified.

3 VISUAL NOTATION FOR ONTOLOGIES

For a better understanding of our visual notation, we need to relate to ontologies both in terms of Description Logic (DL) (Baader et al., 2003; Rudolph, 2011) and the Web Ontology Language (OWL): In OWL, there are classes, properties, and individuals; similarly, in DL we have concepts (classes), roles (properties), and individuals. In order to clearly separate concepts from individuals, we adopt the classical DL distinction of TBox and ABox. In contrast to GrOWL (Krivov et al., 2007), we do not have a separate RBox view but included it in the TBox. Together, TBox and ABox form the knowledge base that can be described by one or more OWL ontologies. We can thus distinguish between three layers that may be visualized: The first two layers follow the TBox and ABox distinction, while their combination – the integrated layer – represents the complete ontology:

1. **Conceptual Layer** – Represents the classes, properties, and their relationships;
2. **Instance Layer** – Represents the individuals and their relationships;
3. **Integrated Layer** – Represents the classes populated with individuals.

3.1 Representation of OWL Elements

We developed graphical representations for a large part of the elements defined by OWL. For some OWL elements, we do not provide a graphical representation, as we either do not think they can be reasonably visualized or consider a text-based presentation of the corresponding information more appropriate. Furthermore, we distinguish between *primary elements*

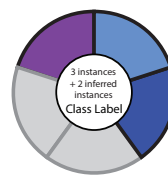


Figure 1: Individuals are visualized as sections of a circle.

that should be visualized as they are key to the understanding of the ontology, and *additional elements* that should only be included in the visualization if needed. In Table 1, we present the primary OWL elements along with their graphical representations and short descriptions. The graphical representations of some additional OWL elements that may also be visualized are listed in Table 2. Note that some of the elements are from the RDF Schema (RDFS) vocabulary¹¹ – they are included in the notation, as they are reused in OWL.

Elements from the ontology header, such as *owl:imports*, *owl:BackwardCompatibleWith*, *owl:incompatibleWith*, *owl:priorVersion*, and *owl:versionInfo*, are best represented as text in an infobox that complements the visualization (as in the later described example of Figure 2). Elements such as *owl:onProperty*, *owl:Ontology*, *owl:AllDifferent*, *owl:differentFrom*, *owl:hasValue*, *owl:distinctMembers*, *owl:Restriction*, *owl:AnnotationProperty*, *owl:OntologyProperty*, *owl:allValuesFrom*, *owl:someValuesFrom*, and *owl:DataRange* (*rdfs:datatype* in OWL 2) are also not visually represented, since they serve as containers for other elements or define constraints for populating the ontology. They are important for editing the ontology or for checking its validity but they can be omitted in the visualization.

Individuals are displayed inside the classes they are instances of. Each individual makes up one section of the circle that represents the class (see Figure 1). Apart from individuals defined by *rdf:type*, the class may include individuals that are defined by an enumeration or alike (e.g. *owl:oneOf*). Superclasses contain the individuals of their subclasses, but these individuals are shown in gray to avoid confusion and misinterpretation.



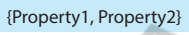


The connectivity of the classes with regard to the domain described by the ontology is indicated by the size of the circles. This size is determined by the number of incoming and outgoing property relations (the more relations, the larger the circle). The *owl:Thing* class has a fixed size for the reason that it does usually not carry important domain information, as we will discuss in the next section.

¹¹<http://www.w3.org/TR/rdf-schema/>

Table 1: Graphical representations of primary OWL elements.

Element	Graphical representation	Description
<i>owl:Class</i>		Circle with round label (<i>rdfs:label</i>) in the middle. Classes from imported ontologies are displayed entirely in gray (incl. the label background).
<i>owl:Thing</i>		Simple circle with label <i>Thing</i> .
<i>owl:ObjectProperty</i> , <i>owl:DatatypeProperty</i>		Line or arc annotated with the label of the property. The label's background color indicates the type of the property (object or datatype property).
<i>rdfs:subClassOf</i> , <i>rdfs:subPropertyOf</i>		Dotted line/arc with an unfilled arrow head at the end pointing to the superclass or superproperty. Subproperties having the same domain and range as their superproperties can alternatively be listed in square brackets within the label of the superproperty.
<i>rdfs:domain</i> , <i>rdfs:range</i>		Arrow starting at the domain and pointing to the range. Datatype properties do not need an arrow, as they are always directed to the literal or data value.
<i>owl:inverseOf</i>		Line/arc with arrow heads at both ends and annotated with the label of the property and its inverse counterpart. Filled arrow heads at the end of the labels indicate the direction of the properties (i.e. their range).
<i>owl:disjointWith</i>		Dashed line/arc with \\\ symbol as label.
<i>owl:FunctionalProperty</i> , <i>owl:InverseFunctionalProperty</i> , <i>owl:TransitiveProperty</i>		Object property representation with an <i>F</i> for functional properties, <i>InvF</i> for inverse functional properties, and <i>T</i> for transitive properties on top of the property label.
<i>owl:SymmetricProperty</i>		Object property representation with identical domain and range, i.e. start and end point of the arrow is the same class.
<i>owl:cardinality</i> , <i>owl:minCardinality</i> , <i>owl:maxCardinality</i>		Exact, minimal, and/or maximal cardinality constraints are written above the property label.
<i>owl:equivalentClass</i>		Colored ring around a class. The labels of all equivalent classes are shown as comma-separated list in the label, each colored in the same font as the corresponding ring.
<i>owl:unionOf</i>		Dashed line/arc with □ symbol as label.
<i>owl:intersectionOf</i>		Dashed line/arc with ◻ symbol as label.
<i>owl:ComplementOf</i>		Dashed line/arc with ◌ symbol as label.
Literals, data types and data values		Rectangle containing the literal or data value.

Table 2: Graphical representations of additional OWL elements.

Element	Graphical representation	Description
<i>owl:DeprecatedClass</i>		Class representation colored in dark gray (with white label background).
<i>owl:DeprecatedProperty</i>		Object/datatype property representation colored in dark gray.
<i>owl:equivalentProperty</i>		Labels of equivalent properties are listed in curly brackets.
<i>rdfs:comment</i> , <i>rdfs:seeAlso</i> , <i>rdfs:isDefinedBy</i> <i>rdfs:label</i> of individuals		Inverted literal representation (i.e. black rectangle with white font).
<i>owl:sameAs</i>		Inverted literal representation listing the labels of the individuals connected with the keyword 'sameAs'.

3.2 Specific Issues

While we developed the visual notation, we came across some issues that we would like to address in the following. One of these issues concerns the *owl:Thing* and *owl:Nothing* elements. According to the OWL specification¹², all classes are subclasses of *owl:Thing*, while *owl:Nothing* is the subclass of all classes. Many visualization approaches do not represent these two elements (Katifori et al., 2007; Guo and Chan, 2011). This is understandable if we consider that *owl:Nothing* is an empty class and that *owl:Thing* is usually not relevant for a particular domain but serves mainly as root class in the ontology. However, at some point we might want to include the *owl:Thing* class in the visualization to facilitate understanding of the ontology (e.g. to indicate that a property does not have a specific domain or range). In these cases, we recommend to use multiple representations of *owl:Thing* in order to not give it an importance in the visualization that it does not deserve.

For the basic set operations *owl:intersectionOf*, *owl:unionOf*, and *owl:ComplementOf*, we reuse the corresponding DL symbols (\sqcap , \sqcup , and \neg), since they are well-known to expert users. Because all three OWL elements define new (anonymous) classes to describe the union, intersection, or complement of other classes, we represented them as circles. If the domain or range of a property links to one of these elements, the line or arc of that property is directly connected to the corresponding circle representation.

Another issue is the question of what happens if certain classes, properties, or individuals do not have an *rdfs:label*. In these cases, we recommend to dis-

play a part of the URI as label (e.g. the characters that follow the last slash or number sign). Related to that, the URIs of classes, properties, or individuals can generally be represented with the graphical representation used for *rdfs:comment* (see Table 2).

We also took into account that color-blindness does not have a strong effect on the readability of the visual representation. In particular, key information is never purely encoded by color. For instance, though different colors are used for object and datatype properties, this information is also clear without color-coding, as object properties always link one individual with another, while datatype properties link individuals with data values.

Finally, it should be noted that the notation does not make a distinction between the three OWL sub-languages OWL Lite, OWL DL, and OWL Full, as this is not relevant for the visual representation. It is also compliant with OWL 2¹³ and all its profiles.

3.3 Advantages

An advantage that is immediately visible from Table 1 is the small number of graphical elements needed to represent a relatively large number of OWL elements. Basically, we used only four types of symbols in different variations for the notation:

- classes = circles (size indicates the connectivity of a class);
- individuals = sections in the circles;
- properties = lines/arcs (with different arrow heads, line types, etc.);

¹²<http://www.w3.org/TR/owl-ref/>

¹³<http://www.w3.org/TR/owl2-overview/>

- literals, data types and values = rectangles.

Maybe the biggest advantage of the notation is the integrated view that allows to represent individuals inside the classes they are instances of.

4 USE CASE

We applied our visual notation to the well-known Friend of a Friend (FOAF)¹⁴ ontology to give an illustration on how it can be used. Although FOAF consists of a relatively small number of classes and properties, it nicely showcases most of the graphical representations of our notation.

4.1 Conceptual Layer

Figure 2 depicts the visual representation of the conceptual layer of the FOAF ontology, i.e. it shows the classes and subclasses along with their property relations. The circles of the classes *Person*, *Agent*, and *Document* have the largest size, since these classes have most property relations. As mentioned in the previous section, we do not consider *owl:Thing* to be of large interest in ontology visualizations. However, we represented it using the multiplication technique mentioned above, since some FOAF properties either explicitly define it as domain or range or do only define one of these two.

As the classes *Spatial Thing*¹⁵, *Person*¹⁶ (from the PIM ontology) and *Concept*¹⁷ are imported from other ontologies, they are displayed in gray (see description of the class notation in Table 1). The colored ring around the circle representing the class *Agent* results from the fact that it is equivalent to the class *Agent*¹⁸ from the Dublin Core vocabulary. Its name is added to the label of the circle and displayed in the same color as the ring (in this case green). The subproperty relations directing to *page* are explicitly shown because the domain and range axioms of the subproperties *weblog*, *tipjar*, *openid*, and *is primary topic of* differ from those of *page*. If this was not the case they could have been represented in the short form that we also used for the subproperty relation of *homepage* in Figure 2 and that is mentioned in Table 1.

The class *Label Property* and the properties *phone*, *focus*, *funded by*, *logo*, *theme*, *DNA checksum*,

¹⁴<http://xmlns.com/foaf/spec/> (version 0.98)

¹⁵http://www.w3.org/2003/01/geo/wgs84_pos

¹⁶<http://www.w3.org/2000/10/swap/pim/contact>

¹⁷<http://www.w3.org/2009/08/skos-reference/skos>

¹⁸<http://purl.org/dc/terms/Agent>

Given name, *nickname*, *title*, and *name* have no relationships with the rest of the classes or properties. Hence, they are listed separately in the top right of Figure 2. Information from the header of the FOAF ontology is shown in the infobox at the bottom right.

4.2 Integrated Layer

We also created a visual representation of the integrated layer of the FOAF ontology using our notation and some sample data. This sample data consists of 28 individuals that are distributed on the FOAF classes as follows: $5 \times Person$, $7 \times Document$, $5 \times Image$, $2 \times Group$, and $9 \times Organization$. Though all these individuals are represented as sections in the circles, the properties of only one selected individual are shown (namely, “Jane Doe”). The FOAF profile of that individual in RDF/XML syntax is as follows:

```
<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/
    22-rdf-syntax-ns#"
  xmlns:foaf="http://xmlns.com/foaf/0.1/">
<foaf:Person rdf:ID="janedoe">
  <foaf:name>
    jane doe
  </foaf:name>
    <foaf:title>
      Mrs.
    </foaf:title>
    <foaf:givenname>
      jane
    </foaf:givenname>
    <foaf:family_name>
      doe
    </foaf:family_name>
  <foaf:nick>
    jane
  </foaf:nick>
  <foaf:mbox rdf:resource=
    "mailto:janedoe@example.com"/>
  <foaf:homepage rdf:resource=
    "www.example.com/janedoe"/>
  <foaf:depiction rdf:resource
    ="janedoe.jpg"/>
  <foaf:workplaceHomepage rdf:resource
    ="www.work.com/janedoe"/>
  <foaf:knows>
    <foaf:Person>
      <foaf:name>
        john doe
      </foaf:name>
      <foaf:mbox rdf:resource
        ="mailto:johndoe@example.com"/>
    </foaf:Person>
  </foaf:knows>
</foaf:Person>
</rdf:RDF>
```

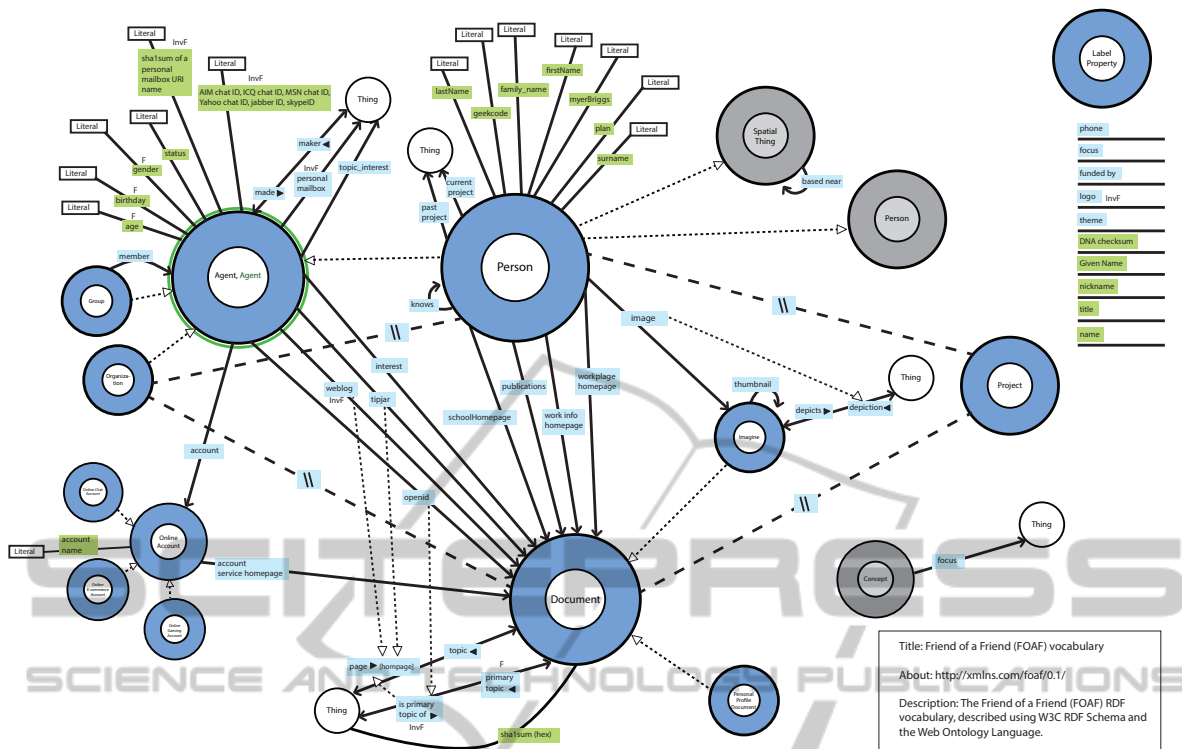


Figure 2: Visual representation of the conceptual layer of the FOAF Ontology (version 0.98).

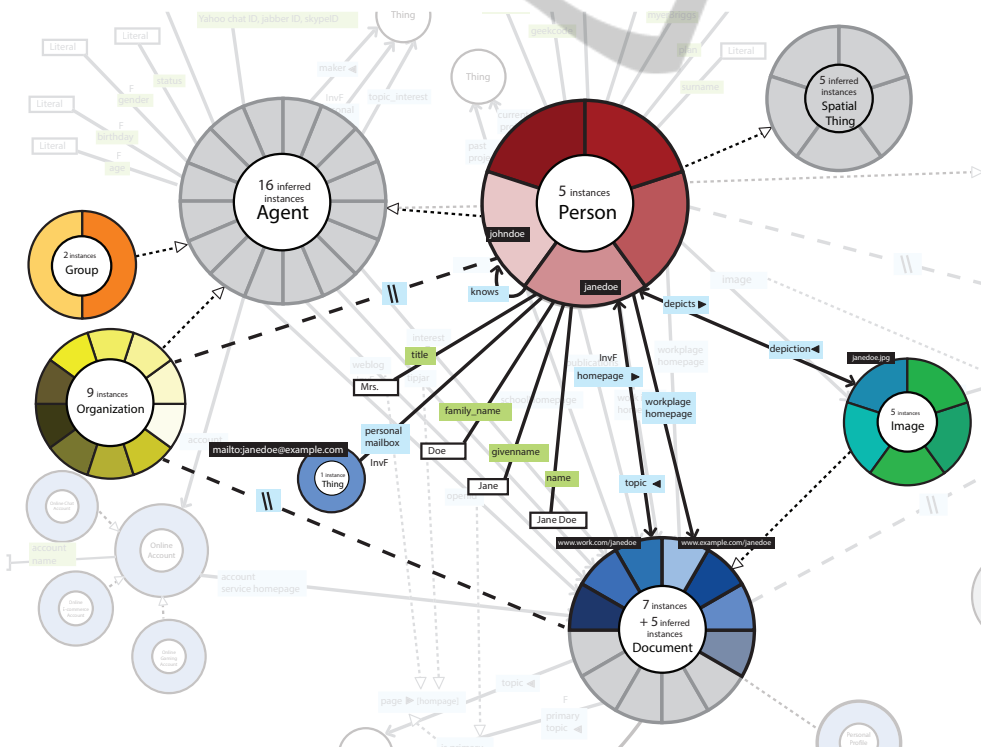


Figure 3: Visual representation of the integrated layer of the FOAF Ontology (with sample data).

Figure 3 shows the integrated view for that individual. We can observe how 'Jane Doe' is linked in

the ontology by following her relations with other individuals and with associated data. The general topol-

ogy of the graph visualization and the positions of the classes are roughly the same as in the conceptual layer presented in Figure 2. Also, the subclass and disjoint relations between the classes are still displayed. However, classes without individuals have been faded out, as the integrated layer focuses on the classes that contain individuals. The number of individuals each class contains is also shown in the integrated layer. The notation distinguishes between individuals that are inferred from subclasses and individuals that are instances of the class itself. Inferred individuals are presented in a light gray while the other individuals have random colors.

5 CONCLUSIONS

In this paper, we presented a visual notation for OWL ontologies. The notation provides a comprehensive yet compact representation of the ontology that requires only a relatively small number of graphical elements. In contrast to most existing approaches, it explicitly defines a graphical representation for each OWL element that can be reasonably visualized. Furthermore, it offers an integrated view on ontologies that shows classes (circles) along with their individuals (sections in the circles) and property relations (connecting lines and arrows). We illustrated the applicability of the visual notation on the example of the FOAF ontology.

The specification of the notation is published under a persistent URL on the web¹⁹ so that it can easily be found and used by others to visualize OWL ontologies. Furthermore, we plan to develop a tool that implements the notation and adds interactive features to it, allowing for a more detailed exploration of the classes, individuals, and relationships in ontologies.

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¹⁹<http://purl.org/vowl/>