How to Document Ontology Design Patterns

Nazifa Karima[1], Karl Hammar[2,3], and Pascal Hitzler[1]

[1] Data Semantics Lab, Wright State University, USA
[2] Department of Computer Science and Informatics, Jönköping University, Sweden
[3] Department of Computer and Information Science, Linköping University, Sweden

Abstract. *Ontology Design Patterns* are reusable building blocks for ontology modelling. As such, Ontology Design Patterns need to be understood by the humans who use them for ontology engineering tasks. In order to make it easier for ontology engineers to understand a previously unknown Ontology Design Pattern, the quality of the documentation of the pattern plays a central role. However, the question how to document Ontology Design Patterns effectively has so far largely been neglected in the research literature. In this paper, we investigate the topic systematically. We discuss the results of three separate surveys to determine the central aspects of good documentation for Ontology Design Patterns. We find that the surveys, which were conducted independently of each other, by two separate groups, essentially agree on the importance of key aspects of documentation.

1 Introduction

Enabling the sharing of data and knowledge across domains was one of the main motivations behind the surge of Semantic Web ontology engineering [1,7]. Very different domains often share concepts like location, time, event, agent, process, etc., that need to be modelled. In such cases, it makes perfect sense for ontology engineers to reuse an ontology, or relevant parts of an ontology, which has already been developed for another domain or use case.

This is where the idea of Ontology Design Patterns (ODPs) comes to play a vital role. ODPs are reusable solutions to recurring ontology modelling problems. Blomqvist and Sandkuhl [4] and Gangemi [6] first proposed this idea with the aim of easing the task of designing ontologies by reusing such well-designed patterns. Besides simplifying ontology engineering by reuse, ODPs also carry the promise of better integrability and interoperability of data across various domains [2].

Unfortunately, despite the general promises, reuse of ontologies or ODPs is not happening yet at significant scale [5]. It thus behooves the Semantic Web community to properly reflect on the different obstacles to reuse, and to work to overcome them. How to develop an ontology [12] or how to reuse ODPs to develop new ontologies [3] has been well-studied in the literature. In particular, the ODP community has adopted or developed best practices to make ODPs reusable for different purposes. However, before an ODP can be reused, it first has to be found and then understood by a potential adopter, and it seems apparent that a high-quality human-readable documentation of an ODP should be very helpful to make reuse easier.

Surprisingly however, best practices of how to properly document ontologies or ODPs have hardly been studied in the literature. E.g., the largest online catalogue of ODPs[4] contains no clear guidelines for proper documentation or showcase examples of well-documented patterns. Although while submitting a pattern, a detailed form needs to be filled, most of the fields are not very clearly explained, e.g. what is meant by *consequence* of a design pattern or what exact set of symbols to use in class diagrams. It is apparent from the current portal that the community has not yet converged on – or even had a serious discussion about – what good ODP documentation would look like. As a result, many ODPs in this portal are uploaded with several documentation fields left blank, which is an obstacle to understanding and thus reusing those patterns.

In this paper we take a step towards rectifying the poor state of research regarding best practices of ODP documentation. We conducted three separate surveys focusing on different aspects of ontologies and ODPs. The first survey is specifically on how to document ODPs, more precisely it was designed to gather a ranking of documentation components in terms of importance. The second survey focuses on discovering barriers to industry adoption of ontologies and ODPs, and inquires about the importance of different aspects of documentation for improving understandability of ODPs in an industrial development setup. The third survey digs deeper into different aspects of ODP documentation.

The first survey was developed by the first and third author; the other two were developed independently by the second author. We became aware of the overlap while the surveys were conducted and realised the potential to use the independently designed investigations for cross-validation. Indeed it turns out, as we will discuss later, that the surveys essentially agree on the end result.

The paper is structured as follows. In Section 2 we discuss the results from the first survey which focused on ranking documentation components in terms of importance. In Section 3 we discuss selected results from two separately conducted surveys which had a somewhat different focus, but which essentially confirm the results from the first survey. In Section 4 we summarise our findings. In Section 5 we conclude and discuss future work.

2 Components of Pattern Documentation

In this section, we discuss the results from a survey[5] that we designed in order to collect opinions about the importance of different components of ODP documentation. We focus on a particularly prominent type of ODP, namely *Content ODPs*, which are used to model generic notions such as event, process, agent, etc., in a reusable way.

The survey participants are students and researchers from the Semantic Web field, who are already familiar with ODPs. We presented the participants with

[4] `http://ontologydesignpatterns.org`

[5] `http://dase.cs.wright.edu/activities/how-document-ontology-design-patterns`

Documentation Components	Rating (percentage)					Total Score
	5	4	3	2	1	
Schema Diagram	74.3	20.0	5.7	0.0	0.0	4.7
Example of Pattern Instantiation	34.3	48.6	11.4	2.9	2.9	4.1
Competency Questions	40.0	34.3	14.3	8.6	2.9	4.0
Axiomatisation	40.0	22.9	31.4	5.7	0.0	4.0
OWL File	28.6	40.0	20.0	8.6	2.9	3.8
Pointers to Related Patterns	17.1	48.6	20.0	14.3	0.0	3.7
Metadata	22.9	34.3	31.4	11.4	0.0	3.7
Set of Example SPARQL Queries	17.1	45.7	20.0	11.4	5.7	3.6
Examples of Available Datasets for Population	2.9	32.4	44.1	17.7	2.9	3.1
RDF Shape (SHACL) Constraints	3.4	17.2	41.4	24.1	13.8	2.7

Table 1. Documentation Components Survey Data

a set of questions on the perceived importance of different documentation components, each component being graded on a five-point scale. Participants could opt to remain anonymous, or to disclose their identity in exchange for later obtaining the results of the survey – almost all participants opted to disclose their identities. Out of the *35* respondents to our open call for participants, about half of them were faculty members at different universities world-wide.

The survey consisted of 10 questions: For each of the documentation components listed in Table 1, participants were asked to indicate on a five-point scale how essential are they considered for a good ODP documentation. The sequence of the questions was randomised in order to avoid bias which may have been introduced otherwise. The survey results can be found in Table 1 in the Rating column. We used a scale ranging from 5 points (indicating 'essential') to 1 point (indicating 'not important') for rating each of the requirement components in question. Then we calculated the average (mean value) of the response rating for each component. The resulting average and corresponding ranking is indicated in Table 1 in the Total Score column.

In the following we take each of the components from the list above, describe current availability of this feature on the ODP portal and discuss its importance for documentation. We also note down our suggestions regarding how these components should best be organised or used in documentation.

Schema Diagram Schema diagram or class diagram has topped the list of required components of an ODP documentation. According to our survey, the main idea of an ODP is expressed best through a diagram using distinct symbols and notations. More than 74% of the respondents considered this component as absolutely essential. Although the ODP site emphasises having the entities and relationships clearly illustrated using diagrams[6], the reality is far from ideal. We found that less than half of the patterns are accompanied by a schema diagram, which makes them very difficult to reuse. We also observe that among the existing diagrams, there is a significant lack of coherence.

[6] `http://ontologydesignpatterns.org/wiki/Odp:Exemplary_ontology`

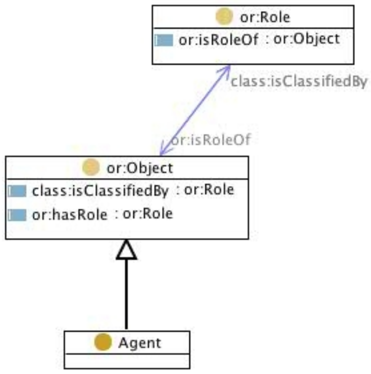

Fig. 1. Agent-Role Pattern

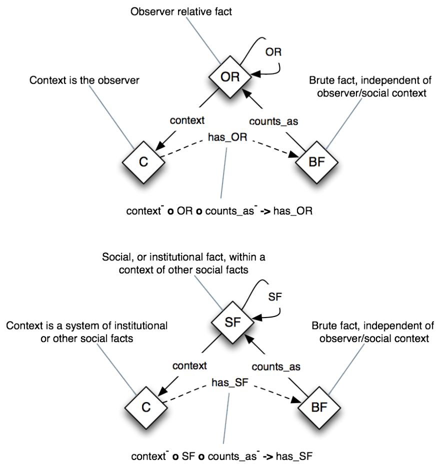

Fig. 2. Social reality Pattern

Currently, there is no standard notation or set of symbols for visually representing ontologies. Although many ontology engineers use UML notations, there is no universal agreement on exact usage of notations or set of symbols. For example in Figure 1 classes are symbolised using rectangles, whereas in Figure 2 squares are used. Some people may use a dotted rectangle to distinguish a pattern structure in an ontology while some others use the same symbol for class representation. Also, usage of various different types of arrow symbols throughout the portal becomes puzzling.

The lack of standardisation leaves room for assumptions which may easily result in wrong interpretations of the diagrams. If people have to spend more time to understand a pattern than it would take them to model from scratch, it seems a fair assumption that they would often opt for the latter, and this may be particularly likely under high resource pressure, e.g., in industry.

Example of Pattern Instantiation According to the survey, the feature which was deemed second most important is examples of populated patterns. We note that this feature received a rating higher than 4, from 82.86% of the participants.

When an ontology is designed it will typically be used to structure some real-life data. A common way of creating patterns is by extracting a recurring feature or module from such an existing ontology. This implies that patterns created in this manner should already at the outset have ample examples of use in real world domains. But when these patterns get uploaded on the ODP portal, such examples of pattern instantiation do not seem to get propagated.

In the current format, the ODP site has a field named 'Known Uses' to mention other ontologies using the same pattern, but for most patterns this field remains empty. The findings presented in Table 1 indicate that it is important to make any known uses of a pattern accessible through documentation on the website, to ensure users have easy access to examples.

Another way of gathering examples of pattern instantiation is when a pattern gets reused. Currently the ODP site holds no option that enables us to link this information. For instance, reuse of patterns such as AgentRole in [14] should be documented, but there is currently no structured way of mapping this information to the corresponding pattern pages in the portal.

Competency Questions The functionality of an ODP is typically expressed in the form of a set of questions that the ODP vocabulary (and data expressed according to that vocabulary) can answer. The presence of a list of such *competency questions*, was by our respondents ranked third most important as component of a proper documentation.

Although the ODP portal has a field for documenting competency questions for each pattern, it remains empty in many cases. It is very difficult to understand the intent and implementation of a pattern without the set of competency questions. For instance, in the chess pattern [14], the sub-pattern 'Move'/'Half-move' is modelled with intention to answer questions like *'What was the n-th move?* or *Find out the complete sequence of moves for game x.* This pattern should be highly reusable for answering similar questions for many other games. Having such questions properly documented would enable a simple web-based search to reduce the difficulty of finding relevant patterns.

Axiomatisation 'Axiomatisation' means a set of human-readable logical expressions which reduces ambiguity by setting constraints on meaning. At this point, the question was agnostic as to the question which logic is used to express the axiomatisation; the emphasis was on human-readability, i.e. the intention was to *not* simply have an OWL file, which is hardly comfortable or quick to read by a human. In practice, axioms could be expressed, e.g. using rules, description logics [7], or predicate logic, or perhaps even non-monotonic logics if some type of (local) world closure were intended [9].

Due to the prevalence of OWL, it seems clear to recommend to use description logics to convey axioms. However in some cases rules are easier to read for humans, and in some cases rules may in fact not be expressible in description logics [10], in which case a rule language or even predicate logic could be used.

OWL File An OWL file capturing the axiomatisation, or the part thereof which is expressible in OWL, is important for people to be able to integrate it into their own ontologies more easily. A significant amount of ODPs on the portal contains an OWL file. In fact, quite a few contain essentially the OWL file only, which is not very helpful in the search of a suitable pattern or for understanding its intent and modelling rationales. But it surely helps after determining the exact pattern one intends to reuse.

Pointers to Related Patterns The Related Patterns field in the ODP portal is rarely populated, and the reasons could be many. First of all, it is impossible for the first pattern in a class of related patterns to link itself to the future patterns that are coming. And, for the newer patterns, there is no concrete way of linking them to a previously existing pattern other than stating the name in string format. As there is no restriction on multiple patterns having the same name, it is difficult to distinguish the exact pattern being referenced. Also, this field should be dynamically updatable so that it gets updated for all related patterns once a new pattern enlists them as related to itself. For example, *Criterion*,[7] *CriterionSetter*[8] and *DescriptionAndSituation*[9] are related patterns. It is very likely that someone having an implementation of one of these patterns would need to know about the other ones as well. There should be a proper linking methodology for patterns related to each other conceptually. A customised search feature based on the related patterns would be extremely helpful too.

Metadata Metadata for a pattern includes, but is not limited to, author names and affiliations, versioning information, contact points, date of creation, mailing list for supporting the pattern, links to published manuscripts, etc. This feature was ranked '3' or higher by almost 90% of the respondents, which implies a lot of demand for this type of information. Unfortunately, the current ODP portal contains only a singular field with a title 'Submitted by' and nothing more where author details could be embedded. Although the ODP site contains a very useful feature for reviewing an ontology design pattern, most of the patterns do not contain any reviews yet. Moreover, all those patterns submitted to any edition of the WOP workshop do have reviews which are not accessible to potential consumers of the patterns. These reviews could be extremely important metadata, if providing reviews could be encouraged by using a reputation-based system like, e.g., StackOverflow.[10]

Set of Example SPARQL Queries At present the most common way of accessing datasets modelled and integrated using ontologies is to run SPARQL queries on them and on possibly inferred knowledge. Providing example SPARQL queries makes it easier to understand the structure of a pattern.

Examples of Available Datasets for Population Adding a number of references to datasets which could be used to populate a given pattern is helpful in order to understand scope and possible application domains of the pattern. It also clarifies cases where a pattern should not be reused. For example, the path of motion of any object through space can be modelled using the Trajectory pattern [8]. Example datasets may come from oceanographic cruises, from geotagged social media posts, or from navigation of users across a web portal. Describing such different application scenarios clarifies the scope of the model.

Constraints using ShEx (Shape Expression) The Shape Expression definition language ShEx is a newly introduced language which enables RDF validation through the declaration of constraints on the RDF model [13]. RDF has certain limitations when it comes to expressing conditions on graph structure, e.g., regarding cardinality constraints. ShEx has been introduced in order to constrain

[7] http://ontologydesignpatterns.org/wiki/Submissions:Criterion
[8] http://ontologydesignpatterns.org/wiki/Submissions:CriterionSetter
[9] http://ontologydesignpatterns.org/wiki/Submissions:DescriptionAndSituation
[10] http://meta.stackexchange.com/questions/7237/how-does-reputation-work

```
chess-o:hasWhitePlayer rdf:type owl:ObjectProperty .
chess-o:Agent rdf:type owl:Class .
chess-o:ChessGame rdf:type owl:Class ;
  rdfs:subClassOf [ rdf:type owl:Restriction ;
     owl:onProperty chess-o:hasWhitePlayer ;
     owl:onClass :Agent ;
     owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger  ] .

chess-o:ChessGame a sh:Shape ;
        sh:property [
        sh:description "The chess white player" ;
        sh:predicate chess-o:hasWhitePlayer ;
        sh:class chess-o:Agent ;
        sh:minCount 1 ;
        sh:maxCount 1 ; ].
```

Fig. 3. Chess cardinalities example in OWL (top) and SHACL (bottom).

the shapes of linked data graphs. Continuing with the chess example, we could use OWL to express that a chess game has exactly one white player, or one could use ShEx, see Figure 3.

Although this component currently is the last one on the list, the concept of RDF Shapes (SHACL) may still be too new for a proper assessment, and so it may have to be revisited. Other constructs of the emerging SHACL/ShEx standards may go clearly beyond OWL, and it is conceivable that it is very useful as a supplement to ODP documentation.

3 Supporting Results from Other Surveys

In addition to the survey described in Section 2, we have also carried out an additional survey, and are in the process of carrying out a third, with an emphasis on respondent preferences regarding Ontology Engineering Methods (including ODP use), and ODP support tool features, respectively. While the former study has received a reasonable number of responses (81), the latter is still ongoing and has at the time of writing only garnered 14 responses, for which reason we only report on it briefly[11].

3.1 Ontology Engineering Methods Survey

This survey consists of a total of 42 questions, of which 9 concern respondent background, and 33 concern ontology engineering method preferences. Responses were anonymous, but respondents could optionally leave their email address to participate in a sweepstakes for gift vouchers, to incentivise respondents.

Respondents were requested to identify themselves based on their level of experience with regard to Ontology Engineering using Semantic Web ontologies as ‘Expert’, ‘Confident’, ‘Somewhat experienced’ and ‘Novice’. In addition,

[11] The associated datasets are available at `http://urn.kb.se/resolve?urn=urn:nbn:se:hj:diva-31513`

	Some exp.	Confident	Expert	All
Tooling Quality	64 %	100 %	92 %	90 %
Documentation Quality	50 %	79 %	69 %	70 %
Method Support	62 %	68 %	64 %	67 %

Table 2. Percentage of respondents considering the respective factor *Very important* or *Critically important* in enabling industry adoption of semantic web ontology technology.

	Some exp.	Confident	Expert	All
Example uses	100 %	75 %	88 %	87 %
Description	75 %	50 %	81 %	73 %
Competency Questions	75 %	29 %	71 %	63 %
Graphical Illustration	75 %	50 %	53 %	55 %
Title	0 %	13 %	56 %	37 %
OWL 2 Profile Adherence	25 %	13 %	13 %	14 %
Size in Classes	0 %	0 %	18 %	10 %
Size in Axioms	0 %	0 %	13 %	7 %

Table 3. Percentage of respondents considering the respective component *Very important* or *Critically important* when evaluating the suitability of an ODP for reuse.

respondents were asked how many years they had worked with Semantic Web ontologies. While self-reported skill level is a notoriously inaccurate measure, we found that the correlation between self-reported experience level group and reported years of experience was very clear, and have therefore elected to treat the self-reported experience level as trustworthy. There was only one respondent who self-reported as being a novice – this response has not been used in analysis.

Table 2 reports the responses to the question *"How important are each of the following factors in enabling industry adoption of semantic web ontology technology?"* (answered on a 5-point scale ranging from "Not important" through "Critically important"). We note in particular three things:

– Confident and expert users have more strongly held opinions on these matters than users with less experience, which is perhaps not very surprising.
– Tooling and documentation quality is by confident and expert users considered more important for industry adoption than method support.
– Expert users consider tooling and documentation quality to be of less importance than confident users. We speculate this may relate to experts not needing tools/documentation to as large a degree themselves, and (possibly incorrectly) generalising this belief to the greater population.

Table 3 reports the responses to the question *"In an ODP search engine or an ODP portal/catalogue, which fields or metadata about an ODP is most important when ascertaining the suitability of that ODP for reuse?"*, answered per the same scale. Only respondents who reported having used ODPs to some extent were given this question, so the number of respondents is fewer than the survey as a whole, at 28. We note that:

- Three of the four top-most ranked components are identical (though ranked slightly differently) to the top-ranked components from the survey described in Section 2. The component that does not match, *Description*, has no direct equivalent in the survey described in Section 2.
- The title of the ODP is, somewhat surprisingly, not considered important in ascertaining the reuse potential of an ODP. We speculate that this may be due to the way the question is phrased; when selecting one ODP out of a list of many, the title is likely to be of more importance, whereas when studying only the one ODP, the title is likely to matter less than other more descriptive fields.

In addition, respondents were in this survey asked to provide free-text responses on ODP documentation. Some interesting comments include:

- *"Much of the documentation is included in research papers; more information with direct sentences should be available outside research publications."* – Expert with 10 years of experience.
- *"In many cases, the documentation is non existent or incomplete."* – Application developer with 2+ years of experience.
- *"IMO, one of the main issue with the re-use of ontology patterns (e.g. those defined at http://ontologydesignpatterns.org/) is the lack of concrete documentation. Generally, the pattern is described at a very generic level and explained based on a particular use case. Furthermore, the graphical representation (when available) are not consistent across patterns making it difficult to adopt."* – Expert with 9+ years of experience
- *"Documentation: some patterns could be ambiguous as, therefore they should be documented in a way the user can be sure they are using the right pattern."* – PhD student with 7 years of experience.

Summarising these opinions we conclude that users want to be able to find suitable ODPs to reuse by searching through the online documentation available as web contents on the web portals, not embedded in scholarly articles or in technical standards documents. The problem with pattern documentation being available only in research papers is that it requires users to already have extensive knowledge in the particular field to know where to look for relevant patterns, which many people trying to reuse an ODP do not have. If the quality of documentation (and in particular the documentation coverage) of the largest online collection of ODPs, the ODP portal, were to be improved such users would have a significantly easier time.

3.2 ODP Tooling Survey

This survey queries for ontologists' preferences and requirements on tooling to support ODP use. The survey is ongoing, and at the time of writing has 14 responses. The respondents vary in age (25-61) and academic background (ranging from MSc degrees through full professorships). The large majority of respondents

Documentation Field	Position Score
Intent	5.91
Competency Questions	4.64
Name	4.09
Solution	3.82
Scenarios	3.45
Domains	3.18
Consequences	2.91

Table 4. Ranking of documentation field utility in ascertaining ODP reusability.

(12) work in academia or research institutes, with a small minority (2) working in industry or government agencies.

Table 4 reports a summary of responses to the question *"Please rank the following ODP documentation fields in terms of how important you think they are to understanding whether an ODP is suitable for reuse in your project"*. The overall position score for each field was calculated by multiplying the score value of each position (7 for first place, 1 for last) with the percentage of respondents who placed the field at said position. Some of the fields provided are more specific and narrow than those listed in the previous two surveys, as they are candidate fields for inclusion under the *Description* documentation component. We again note that Competency Questions are deemed highly important in ascertaining the reusability of a given ODP. We also note the importance of ODP Intent in ascertaining reusability. In the ODP portal this field is defined to, somewhat ambiguously *"[describe] the goal of the Ontology Design Pattern"*[12]. Out of 174 total patterns published there, only 123 have this field populated, indicating there is considerable room for improvement.

The survey also queried respondents on their preference regarding the type of notation used to represent ODPs graphically – we found that the VOWL notation [11] was consistently preferred over alternative notations such as those provided in Protégé and TopBraid Composer.

4 Summary of Findings

Our findings, based on three surveys and a total of 130 respondents, include the following:

- The key ODP documentation fields consistently deemed most important by Semantic Web ontologists include *Graphical Illustration* or *Diagram*, *Examples of ODP Use*, and *Competency Questions.*
- Other key fields that are also reported as being of importance in the three individual surveys (though not queried for and therefore not reported on in all three surveys consistently) include *Axiomatisation*, *Pattern Name* or *Title*, and a *Pattern Description* including in particular the ODP's *Intent.*

[12] `http://ontologydesignpatterns.org/wiki/Property:HasIntent`

Studying the ODP portal, we note that for many ODPs the above given documentation fields, as well as several other documentation fields discussed in this paper, tend to be only partially filled or entirely lacking. Given our finding that the quality of documentation is by 70 % of respondents considered *Very Important* or *Critically Important* to Semantic Web Ontology adoption in industry, this is a cause for concern for the ODP community and the ODPA[13]. This issue is also evident in the free text responses given by survey respondents when asked about their opinion on the state of ODP documentation.

5 Conclusions and Future Work

We have, via three surveys with ODP users of various backgrounds and skill levels, investigated user opinion on ODP documentation structure, and found some consistent preferences. We have noted that in light of this, the ODP community needs to work to improve ODP documentation available in the ODP portal to fill the gaps. The ontology design pattern template and also the ODP site could be improved by adding more items to the questionnaire available to ODP writers

Future work in relation to this includes evaluating the real world impact of different styles or structures of ODP documentation, e.g. through experiments or case studies involving practitioners employing ODPs to solve modelling challenges. Follow-up work to this naturally includes improving such styles or structures of ODP documentation. Finally, in order to simplify ODP use we also believe it is important that the ODP portal search and browsing features be improved, including the pattern categorisation schema.

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