Using ontologies: understanding the user experience

Conference or Workshop Item

Using ontologies

Understanding the user experience

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Abstract. Drawing on 118 responses to a survey of ontology use, this paper describes the experiences of those who create and use ontologies. Responses to questions about language and tool use illustrate the dominant position of OWL and provide information about the OWL profiles and particular Description Logic features used. The paper suggests that further research is required into the difficulties experienced with OWL constructs, and with modelling in OWL. The survey also reports on the use of ontology visualization software, finding that the importance of visualization to ontology users varies considerably. This is also an area which requires further investigation. The use of ontology patterns is examined, drawing on further input from a follow-up study devoted exclusively to this topic. Evidence suggests that pattern creation and use are frequently informal processes and there is a need for improved tools. A classification of ontology users into four groups is suggested. It is proposed that the categorisation of users and user behaviour should be taken into account when designing ontology tools and methodologies. This should enable rigorous, user-specific use cases.

Keywords: ontology use; ontology size; ontology visualization; ontology patterns; Description Logics; OWL profiles.

1 Introduction

In recent decades the use of ontologies has become widespread across a range of application areas. The Handbook on Ontologies (Staab & Studer, 2010) has chapters describing applications in bioinformatics, cultural heritage and recommender systems, besides knowledge management generally. As will be illustrated later, the use of Description Logics (DLs), specifically the variants of OWL, has become the dominant paradigm. With this has come an understanding of the computational properties of the various DLs and the development of efficient reasoners, e.g. see Möller and Haarslev (2009) and Motik (2009). This work has fed into tool development, e.g. the development of the Protégé ontology editor[1] and a variety of ontology visualization

[1] protégé.stanford.edu

tools, e.g. see Katifori et al. (2007). During this time practitioners in particular domains have reported on their experience, e.g. Stevens et al. (2007). Others have undertaken relatively small scale studies of ontology users. For example, Vigo et al. (2014a) report on an interview study of 15 ontology authors and make a number of recommendations for improvement to ontology tool design. In follow-on work a Protégé plug-in has been used to harvest information about the authoring process and enable this process to be studied in detail, see Vigo et al. (2014b). This paper describes a survey which complements these kinds of studies by using a questionnaire to reach a large number of ontology users. The survey also complements the work of researchers who have analyzed actual ontologies. These include: Tempich and Volz (2003), whose goal was to create prototypical ontology corpora for bencharking; Power and Third (2010), who report on the usage of OWL language features; Khan and Blomqvist (2010), who were interested in the frequency of occurrence of content patterns from the ODP portal[2]; and Glimm et al. (2012), who investigated which OWL features were being used by the Linked Data community.

The remainder of this paper is organized as follows. Section 2 describes the survey, how it was conducted, and gives some information about the respondents. In section 3 we look at the various reasons for using ontologies. Section 4 discusses ontology languages and ontology tools. Section 5 discusses ontology size, using a variety of measures. Section 6 discusses the respondents' experiences with visualization tools and reports a range of attitudes to visualization. Section 7 discusses the use of ontology patterns and also reports on a subsequent survey specifically into pattern use. Section 8 then records some final comments from respondents, and section 9 draws some conclusions.

2 The survey and the respondents

The survey was conducted during the first three months of 2013 using the *Survey Expression*[3] tool. Responses were obtained using a number of contacts and relevant mailing lists. The latter included: the ontolog-forum[4], the U.K. Ontology Network[5], the Semantic Web for Life Sciences group and the Description Logic group on LinkedIn, lists maintained by the Open Knowledge Foundation[6], and the internal mailing list within the authors' university department. In all there were 118 respondents. In general, respondents only answered a subset of the questions. However, most questions resulted in several tens of responses. The survey aimed to improve the understanding of how ontology languages and tools are being used. The goal was to use this understanding to identify themes for future research into making ontology use more effective. In line with these aims and goal, the survey sought the respondents'

[2] http://ontologydesignpatterns.org/
[3] www.surveyexpression.com
[4] ontolog-forum@ontolog.cim3.net
[5] ontology-uk@googlegroups.com
[6] okfn-{en|scotland|nl}@lists.okfn.org

views and experiences. In addition, factual information, e.g. about the size of ontologies, was sought in order to provide a context to help understand the other responses.

Respondents were asked to categorize themselves by sector. 116 respondents provided this information, with the following distribution: academic (45%); from research institutes (25%); industrial (17%); and other (13%). They were also asked to give their primary application area. All 118 respondents provided this information and the distribution was: biomedical (31%), business (9%), engineering (19%), physical sciences (7%), social sciences (5%); and other (30%). The 'other' category included computer science and information technology and, to a lesser extent, humanities. 115 people responded to a question about the length of time they had worked with ontologies. 62% had over five years' experience and only 6% had less than one year. More detailed information is provided in Warren (2013).

3 Purposes

Respondents were asked for which purposes they used ontologies. There were eight options plus 'other'. Ignoring 'other', there were 332 responses from 72 respondents, representing an average of 4.6 responses per respondent. Table 1[7] shows the percentage breakdown and a two letter code which is used in the subsequent discussion.

Table 1. Purposes for using ontologies; percentages of 72 respondents

Code	Text in survey	percentages
CM	Conceptual modelling, e.g. formally defining a domain	72%
DI	Data integration, i.e. merging a number of databases	72%
SC	Defining knowledgebase schemas, e.g. as a means of storing and retrieving information	65%
LD	Linked data integration, e.g. linking data from different public knowledgebases	64%
KS	Knowledge sharing, e.g. between individuals in an organisation	56%
HD	Providing common access to heterogeneous data, i.e. providing a common schema for data access	56%
OS	Ontology-based search, i.e. using ontologies to refine search	50%
NL	Supporting natural language processing	26%

These categories were chosen to cover all likely purposes for which ontologies might be used, accepting that there would be some overlap between the categories. In fact, a correlation analysis revealed significant[8] positive correlations between all pairs from DI, KS, LD and SC, with two-sided p values ranging from 0.0006 for DI and SC to 0.0296 for DI and KS. The only other significant correlations were a positive correlation between DI and OS ($p = 0.0356$) and a negative correlation between HD and NL ($p = 0.0496$).

Maximal predictive clustering was also performed to categorize the 72 respondents to this question. This is a clustering technique suitable for binary data in which each

7 Note that, because of the possibility of multiple responses, the percentages total to more than 100%. This is true of a number of other figures and tables in this paper.

8 Throughout this paper 'significant' is taken to mean at the 95% level.

cluster has a 'predictor' vector with components zero or one. The criterion to be maximized is the total number of agreements between each group member and the group predictor. The criterion value was 432 for two clusters and stabilized at close to 500 for eight, nine and ten clusters[9]. A four group classification (criterion = 465) is discussed here because moving to five clusters only increased the criterion by four and led to a cluster with only five members.

The four categories of users were:

- *Conceptualizers:* 16 respondents with a predictor comprising only CM and with an average of 2.2 responses. Users in this category may be interested in using ontologies for modelling, rather than manipulating quantities of data. They might, e.g., be using reasoning to identify inconsistencies in a model.
- *Integrators:* 12 respondents with a predictor comprising DI, HD, LD, SC and with an average of 4.3 responses. These users may be more interested in integrating data from various sources, e.g. a variety of databases.
- *Searchers:* 11 respondents with a predictor comprising CM, LD, OS, SC and with an average of 3.9 responses. Like the integrators, this cluster's predictor includes LD and SC. However, whereas the integrators' predictor includes DI and HD, that for the searchers includes CM and OS. Searchers are more likely to be interested in ontological search, e.g. over the linked data cloud. None of the searchers expressed an interest in heterogeneous data.
- *Multipurpose users:* 33 respondents with a predictor comprising all the response options except NL, and with an average number of responses of 6.2.

4 Languages and tools

Of the 65 respondents to a question about which languages they used, 58 indicated OWL, 56 RDF and 45 RDFS. The other two predefined options, OIL and DAML+OIL received no responses. 11 indicated 'other', which included the Open Biological and Biomedical Ontology format[10], query languages, plus other more specialist languages.

The dominance of OWL was also indicated by the response to a question about which ontology editors are being used. Respondents were given a choice of 12 editors, plus 'other'. Multiple responses were permitted. 63 respondents replied to the question and figure 1 shows the tools for which there was more than one response, indicating the split between OWL and non-OWL. OBO-Edit and Neurolex were amongst the 'other' category; all the others shown were listed in the questionnaire.

When asked which OWL profiles were used, there were 133 responses from 56 respondents, indicating considerable multiple use of profiles. The range of responses is shown in figure 2. Respondents who used DLs were asked to indicate which DL features they used. The choice of features and the responses are shown in table 2. It is noteworthy that a number of people were using the more specialist features, e.g. the

[9] When each point is in a cluster of one, then the maximum of 576 is achieved, i.e. eight responses x 72 respondents.

[10] http://www.obofoundry.org/

four object property characteristics at the bottom of the list (inverse functional, reflexive, asymmetric and irreflexive).

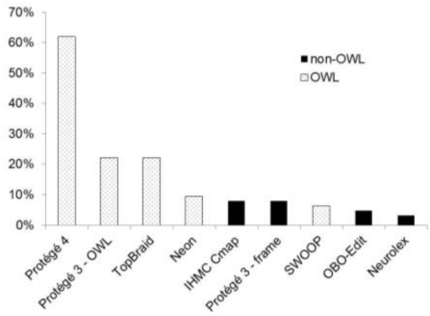

Fig. 1. Usage of ontology editors; percentage of 63 respondents

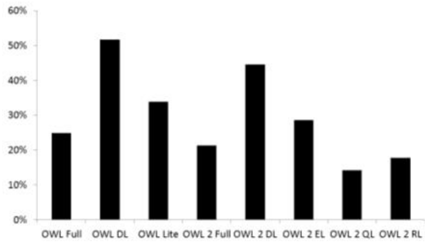

Fig. 2. Usage of OWL profiles; percentage of 56 respondents

Table 2. Usage of DL features; percentage of 47 respondents

object property domain	79%	hasValue restrictions	60%
object property range	77%	cardinality restrictions	51%
disjoint classes	74%	symmetric object property	51%
datatype properties	72%	functional datatype property	51%
intersection of classes	70%	datatype subproperties	49%
transitive object properties	68%	complement of a class	47%
object subproperties	68%	qualified cardinality restriction	43%
union of classes	66%	inverse functional object prop	36%
existential restrictions	66%	reflexive object property	30%
inverse object properties	64%	asymmetric object property	26%
functional object properties	64%	irreflexive object property	17%
universal restrictions	60%		

Respondents made a number of specific suggestions for language extensions. There were also general comments, e.g. the difficulty of design decisions such as classes versus individuals and classes versus properties; and the difficulty of grasping the implications of open world reasoning – one respondent commented that it would be "great if OWL semantics would (partially) support closed world reasoning". Another comment seemed to relate to the difficulty of rigorous modelling, stating that it was not always possible to characterize "strongly semantically".

Amongst the comments on the state of ontology editors were a number referring to the need for the kind of functionality normally found in other system development tools, e.g. auto-completion, version control, and distributed development features. One respondent noted the need for different tools for domain experts and for those "formalizing the ontology". Another commented that "Protégé is not suitable for working together with domain experts".

5 Ontologies and ontology sizes

Respondents were asked to list their most commonly used ontologies, to a maximum of five. 69 people responded and the most common responses were: Dublin Core (49% of respondents), FOAF (29%), Dbpedia (19%), the Gene Ontology (17%) and SKOS (16%). After this came a category comprising the respondents' own ontologies (14%).

For their most commonly used ontologies, they were then asked about the size of those parts of the ontologies with which they actually worked. Specifically, they were asked for the number of classes, individuals, properties, top-level classes and the depth of the hierarchy. This led to 125 responses from 40 respondents. Figure 3 illustrates the enormous range in the size of the ontologies with which respondents were working. Note that the distribution of the number of individuals has a particularly long tail, as to a lesser extent does that for the number of classes.

Many of the ontologies with a very large number of classes were in the biomedical domain. For example, the response in the range '1,000,001 to 3 million' represented the set of ontologies known as the Open Biomedical Ontologies (OBO)[11], which include the Gene Ontology. SNOMED-CT[12] was one of the responses in the range 300,001 to 1 million. Many of the ontologies of depth greater than ten were also in the biomedical domain. They include, for example, the OBO ontologies. Outside the biomedical domain, CYC[13] was an example of an ontology with depth more than ten.

Analysis indicated that the maximum depth of ontology[14] for the conceptualizers was significantly less than for the other three categories combined ($p = 0.020$, based on a Kruskal-Wallis one-way analysis of variance test). The maximum number of classes was also significantly fewer for the conceptualizers ($p = 0.040$). However, there was no significant difference for the maximum number of properties ($p = 0.083$), individuals ($p = 0.134$), and top-level classes ($p = 0.730$).

A Spearman's rank correlation applied to each pair from the dimensions: number of classes, properties, top-level classes and depth (i.e. excluding number of individuals) showed a high degree of positive correlation; the highest p-value was 0.007 (depth versus number of top classes). The number of individuals, on the other hand, was only significantly correlated with the number of properties ($p < 0.001$).

This suggests that the data can be represented by two dimensions; the number of individuals and some representative of the other four dimensions. Figure 4 shows a plot of the number of individuals versus the number of classes. The most striking feature of the plot is the empty area at the bottom right. The ontologies can be regarded as comprising two groups. In one group the number of individuals is greater than ten and in the majority of cases greater than the number of classes. In the other group the number of individuals is in the smallest category of zero to ten, whilst the number of classes occupies a wide range.

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[11] http://www.obofoundry.org
[12] see http://www.ihtsdo.org/
[13] http://www.cyc.com/
[14] I.e. from the up to 5 ontologies which each respondent was able to describe.

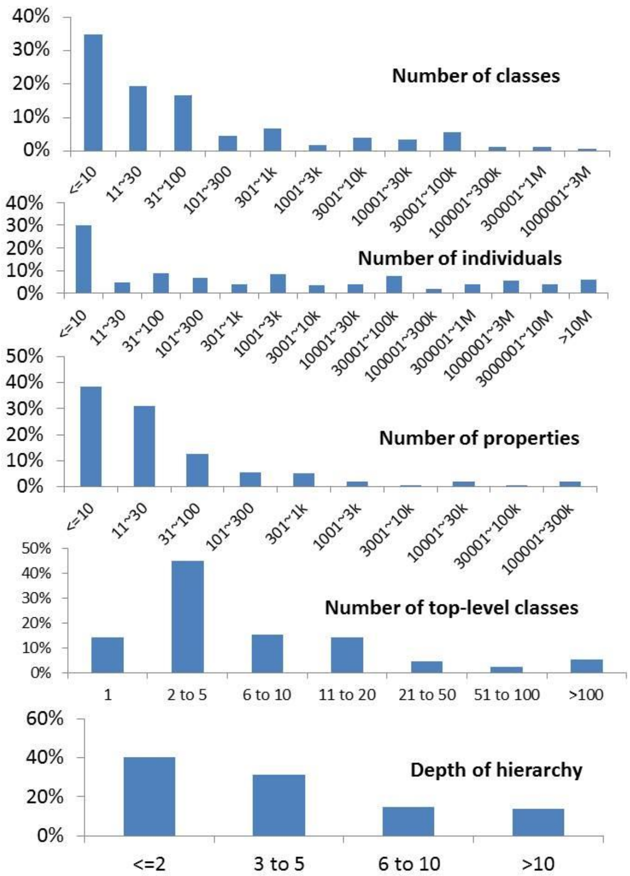
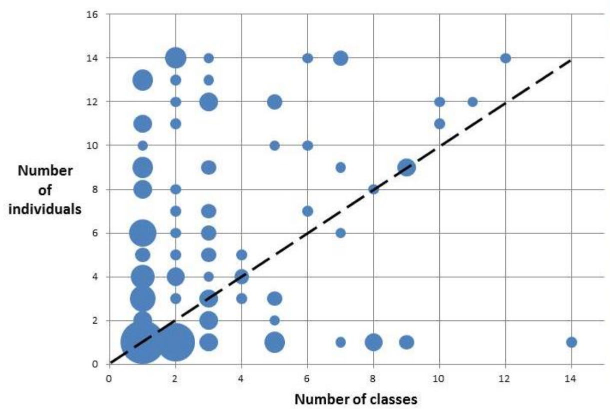


Fig. 3. Ontology size; showing percentage of responses in each size category.



scale	range
1	0–10
2	11–30
3	31-100
4	101-300
5	301–1,000
6	1,001-3,000
7	3,001-10,000
8	10,001-30k
9	30,001-100k
10	100,001-300k
11	300,001-1M
12	1,000,001-30M
13	3,000,001-10M
14	> 10M

Fig. 4. Number of individuals versus number of classes; bubble size represents number of points; dashed line represents equal number of classes and individuals.

6 Visualization

Respondents were asked which ontology visualization tools they used. Figure 5 shows all those tools for which there was more than one response and indicates which of these tools are incorporated into Protégé. Figure 6 gives the percentage breakdown between the various alternative answers to the question 'how useful do you find visualization?', demonstrating a wide range of views. No significant relationship could be discerned between the perceived usefulness of visualization and the size of ontologies being used. However, the ability of each respondent to describe up to five ontologies makes this analysis difficult. A Kruskal-Wallis test revealed no significant difference in the attitudes of the four categories of users ($p = 0.818$).

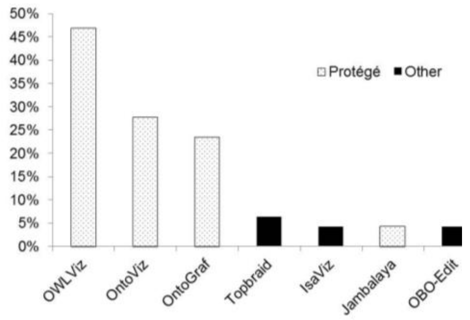


Fig. 5. Usage of ontology visualization tools; percentage of 47 respondents

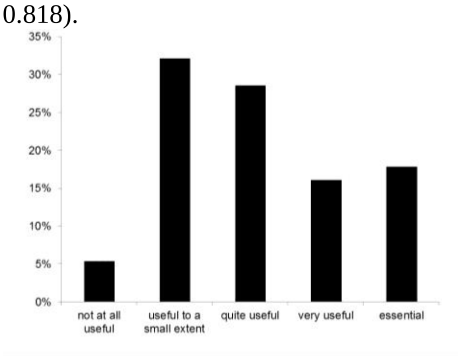


Fig. 6. Perceived usefulness of visualization; percentage of 56 respondents

One respondent wanted to be able to visualize "schema with huge amounts of instance data in order to analyze the effects of changes in real time". Another respondent noted that "visualization is, especially for the end-user, really hard and not task-specific". This echoes comments in other fields, e.g. see Maletic et (2002) al. discussing visualization in software engineering.

7 Patterns

7.1 Original survey

There were 35 responses to a question asking from where ontology patterns were obtained. Table 3 shows the percentage of respondents indicating each of the categories. The category 'other' included the OBO library, see section 5, and the W3C. One point of note is the bias in the biomedical community not to use the generic libraries cited or the Protégé wizard. Of the 14 responses from nine people in the biomedical community, none were for the Protégé wizard and one each, from the same respondent, were for the two libraries. A Pearson χ^2 test revealed that this was significant ($p = 0.039$). One biomedical researcher noted "usually I do generate patterns myself". Respondents were also asked why they used patterns; table 4 shows the response to this question.

Table 3. Sources of ontology patterns; 35 respondents; 61 responses; %age respondents

Own mental models	46%	ODP public catalogue [15]	17%
Own or colleagues‘ collections	37%	Protege wizard	14%
ODP Portal (OntologyDesignPatterns.org)	34%	Other	26%

Table 4. Reasons for using patterns; 33 respondents; 113 responses; %age respondents

Enforce consistency	61%	Reduce modelling mistakes	52%
Make ontology development easier	61%	Speed up ontology development	42%
Encourage best practice	55%	Restrict language features	9%
Make more comprehensible	55%	Other	9%

Of the 32 respondents to a question about the use of tools for creating, editing and using patterns, 20 used no tools "other than standard ontology editing tools". Five of the respondents used the patterns plug-in to Protégé 4 and the remainder used a variety of tools, some specifically developed for ontologies, others generic. Respondents were also asked how they used patterns, specifically whether they imported patterns or recreated them, possibly modified. The great majority (20) indicated only the latter of these two options, five indicated only the former and four indicated both. There were five responses in the 'other' category, including "fully integrated into the tool" and the use of templates. The answers to these two questions indicate the informal way in which patterns are created and used.

Respondents were asked for general comments on their experience with using patterns. One respondent commented that the "best patterns are rather simple, not very complex, basic". A researcher in the biomedical domain expressed the view that there are "seldom some available patterns out there for us to use". This may be because the required patterns are frequently domain-specific rather than generic. Another respondent called for better tool support, stating that "tools should suggest suitable patterns". One comment was about the difficulty of understanding patterns: "initially hard to learn, but provide required functionalities"; this suggests the need for better ways of representing patterns in human-readable form.

7.2 Follow-on patterns survey

A smaller survey was subsequently undertaken specifically to investigate the use of ontology patterns. The survey was broadcast on the same mailing lists as the original survey, and also to some of the respondents to the original survey who expressed an interest in ontology patterns. 13 respondents provided information. A detailed report on the survey results is provided by Warren (2014).

Respondents were asked how they used patterns. Table 5 shows the options and the percentage of respondents indicating each option. Pattern tools being used were: Extreme Design (XD) Tools, see Presutti et al. (2009) and Blomqvist et al. (2010); Tawny OWL, see Lord (2013); Excel and XSLT; and an own unpublished tool. Re-

[15] http://www.gong.manchester.ac.uk/odp/html

spondents were asked how they identified the need for a pattern, with the options "by noticing repeated use of identical or similar structures" and "by systematically analyzing the ontologies I work with, e.g. using a tool". Of the 13 responses there were ten in the first category, two in the second and one who indicated both.

Table 5. Pattern usage; 13 respondents; 19 responses; %age respondents

Use patterns as examples and recreate modified	54%
Import patterns, e.g. as OWL files	46%
Use patterns as examples and recreate unmodified	31%
Generate with a tool specifically designed for pattern creation	31%

Table 6. Creating and storing patterns; 13 respondents; 21 responses

Diagrammatically	54%
Using an ontology editor and storing as, e.g. OWL files	31%
Not written down, from memory	23%
Using a formal language, e.g. MOS, in a text editor	15%
Using an informal language, e.g. English	15%
Other ("own UI to own DBMS", "XSLT source", "to application instance data")	23%

Table 6 shows the response to the question "how do you create and store patterns?" The most striking feature is that over half make use of diagrams. The two respondents from the biomedical domain both used formal languages, but no other technique, whilst none of the other eleven respondents used formal languages. Respondents were asked about the problems they experienced using patterns. Two noted the need for documentation and examples. Other comments included the difficulties of finding the right pattern, and of pattern generation and integration with existing ontologies. One respondent noted that when ontologies are imported, information about patterns is not available. Taken with another comment about the complexity of visualization when several patterns are used simultaneously, this suggests that it would be useful to have editor facilities for viewing patterns embedded in an ontology.

8 Final comments from respondents

At the end of the ontology user survey respondents were asked for any final comments on their experiences with using ontologies. A number of the resultant comments related to the difficulty of modeling with ontologies. One referred to the difficulty of designing classes, which had taken the respondent "many years of learning". Another, working in the biomedical domain, called for a more mature discipline of ontology design: "Ontologies should be built towards use cases and answering biological questions and this is not always the case. Engineering practices in the domain are rarely applied and immature." Related to the point already made about the need for different tools for ontology specialists and domain experts, one respondent noted "…tool support for non-experts working with ontologies / knowledgebases is generally poor". On the positive side, one respondent commented on the experience of using ontologies: "I couldn't build what I build without them".

9 Conclusions

The survey indicates a number of areas for research. The dominance of OWL suggests the importance of research to improve the understandability of OWL constructs. In a follow-up interview, one of the respondents noted that for the ontologist a significant problem is the difficulty of understanding the reason for incorrect entailments. For work on the understandability of OWL entailments see, e.g. Horridge et al. (2011), Nguyen et al. (2012) and Warren et al. (2014).

In the same follow-up interview, the respondent identified the major problem for domain specialists as that of searching and navigating the ontology. One approach to the latter is through visualization. It is clear from the data shown in figure 6 that there is a widely varying appreciation of visualization. Understanding when and for which users visualization works and doesn't work is another important research goal.

Some respondents found modelling difficult, e.g. because of the Open World Assumption. A better understanding of the difficulties could lead to the use of alternative language constructs, e.g. constructs which achieve closure, like the *onlysome* macro described in Horridge et al. (2006).

Section 7 suggested that there is a lack of appropriate methodology and tools for creating and using patterns. Research is needed into the current practices and requirements of users, particularly domain experts outside computing science.

In future research, and in tool development, there needs to be more awareness of the specific targeted end-users and of their goals in using ontologies. The importance of distinguishing between ontology specialists and domain experts has already been made. From the data in our survey we have also suggested a split into four categories of user. We do not propose this as the last word in user categorization. Indeed, it should be viewed as part of a tradition of user and application categorization, starting with the generic categorization of Uschold and Jasper (1999) and continuing with the categorizations specific to biology and medicine made by Shah and Musen (2009) and by Stevens and Lord (2009). Our point is that future developments need to be built on a better understanding of the specific requirements of different user groups. As part of this, precisely defined use cases need to be created. This will support development and lead to more precise criteria by which to evaluate tools and methodologies.

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