OntoMetrics: Application of on-line Ontology Metric Calculation

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Abstract. A lot of work has been done regarding ontology evaluation in the recent years. Automatically calculated indicators are needed in order to assess ontology quality. Manual evaluation of ontologies would be very time consuming. While there is tool support for the detection modelling errors and the violation of ontology modelling guidelines, there is a lack of support for calculating ontology metrics. Many metrics have been proposed that correlate for example with ontology characteristics like Readability, Adaptability, and Reusability. However, no tools have been created or tools are no longer maintained and bound to certain ontology editors. OntoMetrics fills this gap by providing an on-line platform for ontology metric calculation.This paper presents the current status of OntoMetrics, use cases and planned future developments.

Key words: ontology, ontology evaluation, ontology metrics, ontology quality.

1 Introduction

Ontology evaluation is a task that has been subject to research for years. A strong focus has been laid on the selection of appropriate ontologies for reuse in ontology engineering. Considering existing ontologies as sources for the construction of new ones is part of accepted ontology engineering methods. Noy and McGuinnes for example have an explicit reuse-step in their method [1]. With the increasing number of existing ontologies and thus an increasing number of candidates for reuse in a certain domain, automated evaluation of ontologies is required. Swoogle[1] as a search engine for ontologies calculates an ontology rank for the order of the presented search results [2]. Additionally, swoogle calculates some basic ontology-metrics that become part of the available ontology meta-data. Besides the reuse aspect, ontology quality should be monitored throughout the ontology life-cycle. This includes the creation of ontologies but also their maintenance. Again, there is a need for automated evaluation due to the complexity of ontologies and knowledgebases. A majority of the approaches suggests metric calculation in order to assess ontology characteristics (examples in [3, 4, 5, 6, 7, 8]).

Existing Ontology Development Environments like Protégé provide only basic support for ontology evaluation. Plug-ins for ontology evaluation that have

[1] `http://swoogle.umbc.edu/`

been developed are bound to a certain ontology editor. This comes with some disadvantages: (a) the user is forced to use the editor the plug-in is developed for, (b) plug-ins tend to be outdated if new editor versions evolve (see also [9]), and (c) discontinuation of editor development makes the plug-in unavailable for use. Furthermore, a number of approaches remained in the status of prototypes or just proposals. As a consequence, approaches to automated ontology evaluation are rarely available for empirical evaluation and practical use. So far, web based solutions seem to be the best at hand because of their public availability and their independence from ontology development environments. The OntoMetrics[2] on-line platform has been developed as a consequence of this discussion by:

1. Providing a web-based platform for ontology metric calculation.
2. Supporting a standardized ontology format (OWL 2).
3. Collecting the theory behind the metrics and their validation.
4. Providing machine-readable XML-output for further analysis.

After an introduction of the field of ontology metrics in the next section, the remainder of this paper is dedicated to the OntoMetrics on-line platform. Section 3 describes the current platform functionality and the general usage scenarios. Examples of ontology metric calculation scneraios are provided in section 4. Finally, the future development roadmap is drawn in section 5.

2 Ontology Metrics for Ontology Evaluation

Similarly to *Software Quality Metrics*, *Ontology Metrics* are quantifiers that can be determined using a defined measurement procedure that is applied to the ontology (software) [5]. A correlation between the calculated metrics and certain quality criteria is assumed or – even better – empirically validated. Publications on ontology metrics often see this validation as a problem (see for example [10, 11, 8]). In order have a better validation of the proposed metrics, the metrics calculation needs to be made available, reproducible, and analysable. A platform like OntoMetrics addresses these issues.

Throughout the *Ontology Life-cycle* different aspects (*Ontology Scopes*) of the ontology have to be assessed regarding their quality. Furthermore, with each step in the life-cycle new ontology development artefacts (*Ontology Layers*) become available for evaluation. Thus, applicability of *Ontology Evaluation Methods* and the importance of *Ontology Quality Criteria* depend on the phases of the *Ontology Life-cycle*. As a results, five dimensions for description of metric based ontology evaluation can be found: *(I) Ontology Scopes, (II) Ontology Layers, (III) Ontology Life-cycle, (IV) Ontology Quality Criteria,* and *(V) Ontology Evaluation Methods*. Pak and Zhou [12] define quite similar dimensions in their ontology evaluation framework.

Figure 1 illustrates the described dependencies throughout the *Ontology Life-cycle*. While the *Vocabulary* of an ontology is defined during *Conceptualization*,

[2] `http://www.ontometrics.org`

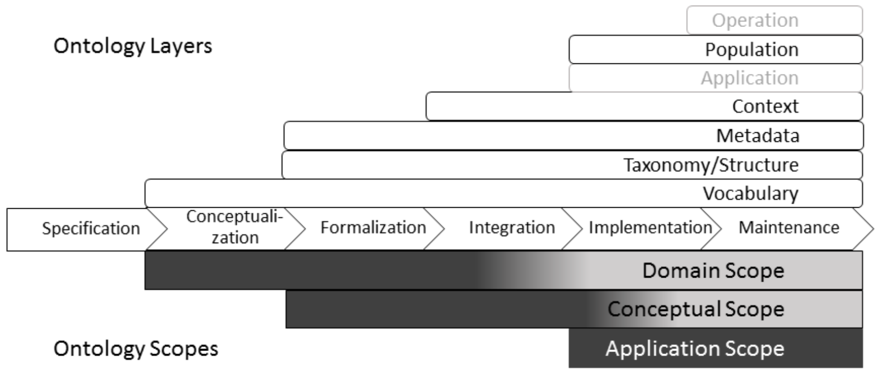

Fig. 1. Ontology Layers and Scopes during Ontology Life-cycle

formal *Metadata* and ontology *Taxonomy/Structure* become available for analysis during *Formalization.* With the *Integration* of other ontologies, the *Context* of the ontology is set. *Implementation* then adds *Population* and the *Application* within an information system that uses the ontology. *Operation*al data of the information system becomes available when the system is in use and the ontology is in the *Maintenance* phase. Except for *Operation* and *Application* layer (greyed in figure 1), data of all ontology layers is part of the OWL 2 specification and thus can be evaluated by an on-line platform like OntoMetrics. For the *Ontology Scope* it is depicted, when they can be addressed in the ontology life-cycle and at which phases they are most important (dark areas in figure 1):

Domain Scope: How well does the ontology represent the real world?
Generally, data driven evaluation methods can be applied here like presented by Alani et al. [13]. These methods either use text corpora of the represented domain or golden standard ontologies and compare the evaluated ontology to them. *Ontology Quality Criteria* that are evaluated in the *Domain Scope* (correctness of the ontology) are *Accuracy, Completeness, Conciseness,* and *Consistency* [14].

Conceptual Scope: What is the quality of the ontology in analogy to internal software quality characteristics?
Generally, ontology structure based methods can be applied here. We divide between schema metrics suggested for example by Tartir et al. [8] that consider the special semantics of the ontology schema graph elements and graph-based metrics that calculate general graph characteristics like size and breadth for the taxonomical part of the ontology (for example Gangemi et al.[5]). Furthermore, Gangemi et al. suggest metrics based on annotations within the ontology. *Ontology Quality Criteria* that are evaluated in the *Conceptual Scope* are for example *Computational Efficiency, Adaptability, Clarity* [14]*, Reusability* [15], and *Readability* [8].

Application Scope: How well does the ontology in use as component of an ontology based information system (external software quality)?
The third aspect of evaluation is the external quality of an ontology in conjunction with an information system. Thus, the characteristics of the used information system have an influence on the on the measured quality. Task-based methods as described by Porzel and Malaka [16] can be used here. Another possibility is the assessment of usage statistics [10]. However, little effort has been spent on the development and validation of methods that evaluate ontologies within the *Application Scope*. A reason lies in the effort of evaluating different ontologies for the use within the same information system or vice versa to evaluate the same ontology in different information systems in order to exclude the information system's influence on the measurement. Nonetheless, monitoring changes in the metrics that are used to measure these criteria should provide information regarding ontology maintenance. *Ontology Quality Criteria* that can be evaluated in the *Application Scope* are *Efficiency, Effectivity, Accuracy* and general *Value* (measured by Popularity).

Table 1 shows the accessibility of *Ontology Layer*s to the *Evaluation Method*s. A + marks combinations if there are *Evaluation Method*s that calculate metrics for the respective *Ontology Layer*. In the case of a -, there is no support. *Operation* and *Application* layers are not considered. Data Driven and Golden Standard based methods rely on additional data – either provided by domain specific text corpora or by domain specific best practice ontologies (golden standard). A platform like OntoMetrics provides little coverage for the *Domain Scope* unless the required additional data is accessible. *Application Scope* is also poorly covered as stated before. Thus, the main focus of OntoMetrics is on the *Conceptual Scope* and hence on *Conceptualisation*, *Formalization* and *Integration* phases of the ontology life-cycle.

3 OntoMetrics – Current State and Intended Use

At its current state, the OntoMetrics platform has the following functional areas:

- A web-interface to upload ontologies and to calculate a set of *Ontology Quality Metrics* for them.
- An XML-download of calculated *Ontology Quality Metrics*.
- A wiki that explains the semantics and the calculation of the *Ontology Quality Metrics*.

The web interface for metric calculation accepts ontologies represented in OWL or RDF using RDF-XML representation. The ontologies can either be uploaded by a file picker or copied into a text field. Alternatively, an ontology URI can be used to specify which ontology has to be analysed. Prior to the metric calculation, the user can choose via a selector box, which kind of metrics should be calculated. The class metrics which have been adopted from Tartir et al. [8] cause a higher computational effort. Here, special metrics for each named class

Table 1. Evaluation Methods and Ontology Layers

<table>
<tr><th colspan="2" rowspan="2">Ontology Scope</th><th rowspan="2">Ontology Layer</th><th colspan="3">Evaluation Method</th></tr>
<tr><th>Data-driven</th><th>Golden Standard</th><th>Structure Analysis</th></tr>
<tr><td rowspan="5"></td><td rowspan="3">Application</td><td>Operation</td><td></td><td></td><td></td></tr>
<tr><td>Population</td><td>+</td><td>-</td><td>+</td></tr>
<tr><td>Application</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Conceptual</td><td>Context</td><td>-</td><td>-</td><td>+</td></tr>
<tr><td>Metadata</td><td>-</td><td>-</td><td>+</td></tr>
<tr><td rowspan="2">Domain</td><td>Taxonomy/ Structure</td><td>-</td><td>+</td><td>+</td></tr>
<tr><td></td><td>Vocabulary</td><td>+</td><td>+</td><td>-</td></tr>
</table>

within the ontology are calculated. When the calculation has been started by the 'Start Calculation'-Button, the platform tries to retrieve all ontologies that are imported to the analysed ontology. If one of the imports is not available, a specification of the problem is provided. On the results page, the metrics can be directly analysed. A download of the results in XML-format is available as well.

Table 2 shows the metrics that can currently be calculated using OntoMetrics in addition to the standard OWL-API counting metrics. There are four general types of metrics. *Schema Metrics* take the special meaning of the OWL-Schema-definition constructs into account for the calculation of metrics on the ontology structure. *Graph Metrics* are metrics that can be generally applied to graphs (esp. trees). In the case of ontology evaluation, they are calculated for the taxonomy tree of the ontology. *Knowledgebase Metrics* do not only assess the type structure of an ontology but also instances that populate the ontology. At last, *Class Metrics* narrow the focus to single class evaluation.

For a explanation of the metrics, the reader can refer to the OntoMetrics-Wiki or to the given sources in the table. Although mainly two sources are given with Gangemi et al. [17] and Tartir et al. [8], most of these metrics have also been proposed by other authors or are basic graph metrics.

The table-head contains quality criteria as mentioned in section 2. For more comprehensive semantics of the criteria, refer to [12]. Those quality criteria have been selected, where a correlation to the calculated metrics has been proposed in the literature. Thus, for each of the quality criteria at least one metric is available in conjunction with the proposed direction of correlation. '+' means positive correlation and '−" negative correlation. As expected from the previous discussion, quality criteria that are relevant within the *Domain* and the *Application Scope* are under-represented. Furthermore, the Metric-Criteria-Matrix provided by table 2 is sparsely filled. Some of the metrics have just been proposed as an indicator for good ontology quality without explicitly naming quality criteria (e.g. in [8]). In consequence, there is a lot of room for further research on ontology metrics. The following usage scenarios in research and practice are seen for the OntoMetrics platform:

1. Empirical validation of proposed correlations between metrics and quality criteria regarding strength and significance.
2. Determination of influences like the ontology usage context on these correlations.
3. Determination of of best practise metric profiles and values for certain domains and usage contexts.
4. Analysis of Domain Specific Languages (DSL) and Models formulated in these languages if an OWL representation is available.[3]
5. Practical ontology quality assessment by calculating validated metrics.
6. Practical ontology quality assessment by monitoring anomalies in calculated metric values.
7. Proposal and validation of new metrics and their application by providing them on OntoMetrics.
8. Internal collection of evaluated ontologies for later calculation and validation of new metrics or theories regarding ontologies.

OntoMetrics supports these usage scenarios by providing easy, reliable and repeatable access to metric calculation. The XML-Representation of the calculation can be used for further automated processing of the results.Additionally, the wiki gives orientation regarding the application of already implemented metrics and also by providing room for the discussion of new ideas. Researchers are invited to contribute to the platform with their own proposals of quality metrics. This can be done by presenting a metric proposal for discussion in the wiki or by providing an implementation that can be included in the platform and thus would be available for validation and use on a broad scale.

4 Ontometrics-Usage Examples

In the following, two examples are provided that illustrate the usage scenarios presented in section 3.

4.1 Validation of Ontology Metrics for Ontology Design Patterns (ODP)

The validation of of ontology metrics for Ontology Design Patterns (ODP) in [15] is an example for point 1 of the OntoMetrics usage scenarios in section 3.

[3] For example Archimate models from the Enterprise Architecture Domain can be transformed to OWL using the toolset provided by the Timbus project: `https://opensourceprojects.eu/p/timbus/context-model/converters/wiki/Home/`

Table 2. OntoMetrics – Quality-Metrics-and-Criteria-Matrix

Metric	**Accuracy**	**Understandability**	**Cohesion**	**Comp. Efficiency**	**Conciseness**
Schema Metrics[17]					
Attribute Richness [8]	+ [8]				
Inheritance Richness [8]	+ [8]				
Relationship Richness [8]	+ [8]				
Attribute Class Ratio					
Equivalence Ratio					
Axiom/Class Ratio					
Inverse Relations Ratio					
Class/Relation Ratio					
Graph Metrics [17]					
Absolute root cardinality			+ [18]		
Absolute leaf cardinality		+[15]	+ [18]		
Absolute sibling cardinality					
Absolute depth		- [17]			
Average depth	+ [11]	- [17]			
Maximal depth	+ [11]	- [17]			
Absolute breadth		- [17]			
Average breadth	+ [11]	- [17]			
Maximal breadth	+ [11]	- [17]			
Ratio of leaf fan-outness					
Ratio of sibling fan-outness					
Tangledness		- [17]		- [17]	
Total number of paths					
Average number of paths					
ADIT-LN			+ [18]		
Knowledgebase Metrics [8]					
Average Population					+ [8]
Class Richness					+ [8]
Class Metrics [8]					
Class connectivity					
Class fulness					
Class importance					
Class inheritance richness	+ [8]				
Class readability		+ [8]			
Class relationship richness	+ [8]				
Class children count					+ [8]
Class instances count					
Class properties count					

Ontology design patterns (ODP) have been proposed as encodings of best practices supporting ontology construction by facilitating reuse of proven solution principles. Different kinds of ODP have been proposed, like logical, transformation or content ODP, which represent different aspects of best practices (see [19, 20, 21]). This work focuses specifically on Content ODP and on investigating the transferability of ontology quality metrics to Content ODP. The long term objective is to create an instrument for quality assurance of ODP. After a pre-selection of *Ontology Metrics* based on their general applicability to *Content ODP*, their correlation to *Ontology Quality Criteria* is investigated with respect to:

- *Clarity:* Recognition of all concepts, relationships, and their correspondences.
- *Understandability:* Comprehension of all concepts, relationships, their correspondences, and their meaning.
- *Adaptability* to a given use case (The users got the task to adapt the respective pattern prior to evaluation).
- *Reusability:* for example as a part of a larger pattern.

In an experiment (27 participants), nine ODP have been evaluated regarding these criteria. For the experiment, the participants have been provided with the ontology graph, the labels of used semantic relations, and the ontology annotations (Recognition annotations) on paper. In consequence, the role of attributes and attribute based metrics could not be evaluated in the experiments. Furthermore, the participants had to design and draw an ontology containing the evaluated ODP. This was done in order to foster the examination of ODP by the participants. The resulting ontologies have not been assessed. The ODP evaluation according to the four criteria (*Clarity, Understandability, Adaptability,* and *Reusability*) was based on a Likert-scale containing the values 1 (very good), 2 (good), 3 (satisfactory), 4 (fair), and 5 (unsatisfactory). The rating was done by the participants according to their perception. Figure 2 shows the average rating of each ODP with regard to the criteria. Afterwards, correlations between experiment-based evaluation results and calculated *Ontology Metrics* have been evaluated. This was based on the Pearson correlation. Two aspects have been evaluated: (1) the significance of the correlation and (2) the strength of the correlation. A correlation had been considered significant if the error probability (based on the Student distribution) was below 5%. For the correlation strength, a Pearson coefficient $|r| \geq 0.5$ had been set as the threshold. Table 3 shows the results for those metrics that are available on OntoMetrics. Values matching the thresholds are marked green. Based on this assessment, metrics that seem to be appropriate for *Content ODP* evaluation are marked green as well.

At the time of the experiments, OntoMetrics was not available. Metrics have been calculated manually what increased effort and presented a source for possible errors. On the base of OntoMetrics that also provides metrics that have not been used in the study at hand [15], an assessment of the applicability of these additional metrics to *Content ODP* would pose little effort. The identified metrics could be used for (semi-)automated quality assurance of *Content ODP*.

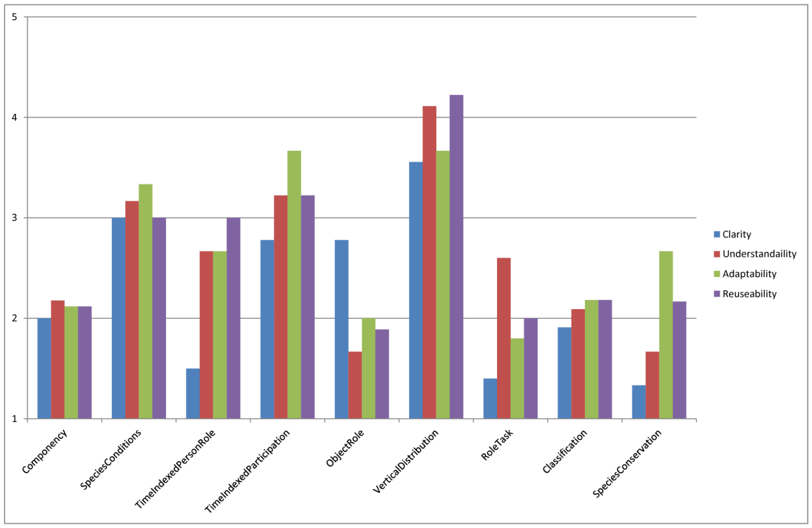

Fig. 2. Experimental Evaluation of Content ODP

Table 3. Correlations of Quality Criteria and Ontology Metrics for Content ODP

Correlation Strength					Correlation Significance (Error Probability)			
Clarity	Understandability	Adaptability	Reusability	Metric Symbol	Clarity	Understandability	Adaptability	Reusability
0,250776646	0,499779215	0,432058191	0,504548665	Absolute Depth	0,02679038	0,00000319	0,00007816	0,00000248
0,313647082	0,279560051	0,297776833	0,335595026	Average Depth	0,00516970	0,01318314	0,00810199	0,00266746
0,295559616	0,444303815	0,436415839	Maximum	Maximal Depth	0,00861058	0,00004602	0,00006489	0,00001405
0,307338226	0,526964957	0,45615236	0,526579671	Absolute Depth	0,00619838	0,00000072	0,00002703	0,00000073
0,14655107	0,413395249	0,327527356	0,416521697	Average Depth	0,20042816	0,00016869	0,00342096	0,00014876
0,461706214	0,632487516	0,545385767	0,58171873	Maximal Depth	0,00002092	0,00000000	0,00000024	0,00000002
0,461706214	0,632487516	0,545385767	0,58171873	Absolute Leaf Cardinality	0,00002092	0,00000000	0,00000024	0,00000002
0,312573259	0,337482338	0,239521256	0,17955178	Ratio of Leaf Fan-outness	0,00533332	0,00251424	0,03467869	0,11572604
-0,312573259	-0,337482338	-0,239521256	-0,17955178	Ratio of Sibling Fan-outness	0,00533332	0,00251424	0,03467869	0,11572604
0,307338226	0,526964957	0,45615236	0,526579671	Number of Classes	0,00619838	0,00000072	0,00002703	0,00000073
0,249903773	0,4835291	0,416258197	0,492709387	Total Number of Paths	0,02734232	0,00000731	0,00015035	0,00000460
0,3247366	0,371440524	0,335130563	0,247971892	Relationship Richness	0,00372275	0,00081353	0,00270642	0,02859817
-0,117374106	0,010997711	0,26419837	0,12810475	Attribute Richness	0,30610626	0,92386697	0,01942045	0,26367943
0,351440918	0,480948885	0,431240883	0,461056731	Inheritance Richness	0,00160486	0,00000831	0,00008092	0,00002156

4.2 Analysis of Enterprise Architecture Languages and Models

The analysis of Enterprise Architecture (EA) languages and models is an example for the application of OntoMetrics to Domain Specific Languages (DSL) as suggested in point 4 of the usage scenarios in section 3. Ontology evaluation can be used to assess the conceptual part of DSL specifications. *Quality Criteria* like *Coverage, Conciseness, Clarity,* and *Reusability* can be evaluated. Antunes et al. present in [22] an ontology-based approach for *Enterprise Architecture Analysis*. Their approach comes with an ontology[4] that represents the ArchiMate® language constructs and their relationships. ArchiMate® is a standard language for *Enterprise Architecture Modelling* that is maintained by the OpenGroup[5]. Furthermore, Antunes et al. provide a tool to convert ArchiMate models that are created with the Archi toolset[6] to an OWL representation.

In consequence, OntoMetrics can be used to evaluate the provided ArchiMate® conceptualization as well as models that have been created with the Archi toolset. So far, there is not enough empirical data available in order to give a comprehensive assessment. However, some exemplary statements can be drawn from first analysis results. For example, the ontology representing ArchiMate® has an *Average Number of Paths* of 1.0. This means that there exists in average 1 path from the root to each of the classes (language concepts) within the inheritance tree. In consequence, no multiple inheritance is used. Thus, a 'good'*Readability* of the language concepts is assumed. Including model instances into the evaluation, for example the importance of certain language concepts can be assessed or vice versa the coverage of a model. Figure 3 shows the *Class Importance* of ArchiMate® concepts based on the Archisurance model that is based on a case study by the OpenGroup. The figure only contains classes that have more than 1 per cent of the total number of individuals in the model. These are 20 out of 55 concepts (*Total Number of Classes*) . The most important classes are *BusinessActor* and *BusinessObject*. Thus, a conclusion might be to provide specializations of these classes in order to improve *Clarity* since the semantics may be to unspecific at present. However, this conclusion should only be drawn when a broad base of models is available for evaluation. Furthermore, it could be determined which ArchiMate® concepts are typically used in certain contexts an which ones are superfluous. Vice versa, models for a certain context can be evaluated regarding the usage of typical concepts of that context.

5 Conclusion and Outlook

At its present state, OntoMetrics is a lightweight, handy tool for comparable, metric based ontology evaluation. In combination with the Quality-Metrics-and-Criteria-Matrix (table 2) it can be used to assess ontologies using already accepted and suggested metrics. The main focus lies on the *Conceptual Scope*.

[4] `http://timbus.teco.edu/ontologies/DIO.owl`
[5] `http://pubs.opengroup.org/architecture/archimate2-doc/toc.html`
[6] `http://archimatetool.com/`

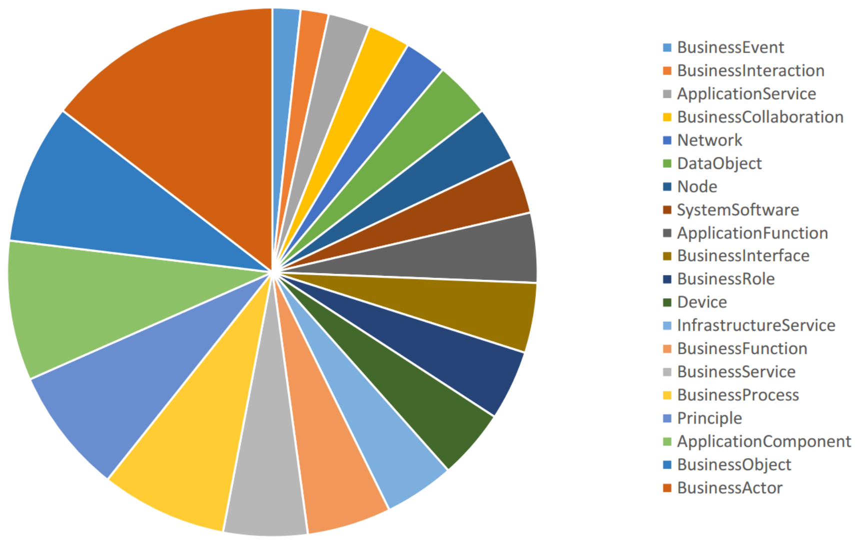

Fig. 3. Class Importance of ArchiMate® concepts based on the Archisurance Model

However, *Domain Scope* and *Application Scope* are partially covered as described in section 2. The wiki provides information on the theoretical background of the calculated metrics. For the future development of the OntoMetrics platform, three main directions are planned:

1. **Enhance the knowledgebase of OntoMetrics**
   The information in the wiki regarding the proposed metrics is planned to be extended by additional sources, use case descriptions and systematizations.
2. **Provide additional quality metrics**
   New metrics of the introduced types can be added with little effort via defined programming interfaces. Furthermore, a support of data driven ontology metrics calculation is planned.
3. **Extend the base functionality of OntoMetrics**
   In order to allow tool integration of OntoMetrics, a Web-Service that provides metric calculation functionality is planned.

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