Ontology Metrics as a Service (OMaaS)

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Abstract: The use of automatically calculated metrics for the evaluation of ontologies can provide impartial support for knowledge engineers. However, even though the use of ontological representations is unabated – in opposite expected to rise through the increasing use of AI technologies – most ontology evaluation tools today are no longer available or outdated. At the same time, due to the growth of the computational cloud, service-driven architectures are on the rise, and enterprises tend to prefer to consume services in a platform- or software as a service model. In this paper, we argue that the change of the IT-landscape also requires a change in how we offer and consume ontology metrics. This hypothesis is backed by an industrial use-case of Robert Bosch GmbH and their application of ontologies, as well as their need and requirements for ontology evaluation. It motivated the extension of the tool OntoMetrics with a REST-interface, offering a public endpoint for ontology metrics on the Internet.

1 INTRODUCTION

Ontologies, widely regarded as „a formal specification of a shared conceptualization" (Borst, 1997), are not new to the scientific community. The importance of an ontological knowledge exchange format for AI was outlined by Matthew Ginsberg as soon as 1991 (Ginsberg, 1991). With the introduction of the Semantic Web in 2001, where ontologies intermediate a meaning between the representation and data layer (Berners-Lee et al., 2001) and recommendation of the W3C for RDF, RDF(S), and OWL a little later, this technology got attention from a broader set of audience and is now being used by various research disciplines or industries like medicine, biology, geography, astronomy, defense, automotive or aerospace (Grau et al., 2008, p. 309). The possible applications for computational ontologies are diverse. Examples are, among others, the knowledge management system of the food and agriculture organization of the united nations, where all reports of the fisheries and aquaculture department are integrated into a network of ontologies for enhanced information sharing, at the same time enlarging the open linked data repository (Caracciolo et al., 2012) or the storing of genomes, their molecular functions, locations or biological processes (Kelso et al., 2010). Ontologies are even used in the security-sensitive military branch, allowing queries like "which helicopters are used only for attacking" (Mishra & Jain, 2019).

However, with the beginning of the introduction of ontologies in various branches, a problem arose. The classical engineering processes, like the "Ontology Engineering Methodology" (Sure et al., 2009) or the distributed NeOn Methodology (Suárez-Figueroa, Gómez-Pérez, & Fernández-López, 2012), heavily build on the involvement of knowledge engineers for the engineering of the ontology itself. But not only are ontology engineers a scarce resource (Suárez-Figueroa, Gómez-Pérez, Motta, & Gangemi, 2012), often the development of large ontologies is highly decentralized and requires a participative, self-organizing structure of domain experts. Methodologies like DILIGENT (Pinto et al., 2009) propose a framework for this changing landscape by putting more responsibilities on the domain experts

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and end-users, withdrawing the knowledge engineer to a controlling and advisory role.

This puts the validation of the quality of an ontology at an even more central position. Many quality criteria like accuracy, adaptability, clarity, completeness, computational efficiency, conciseness, consistency, or organizational fitness (Vrandečić, 2009) are highly desirable. But the path to the perfect ontology or even the measurement of such is difficult to achieve. Even the quality ratings of experienced knowledge engineers tend to be highly subjective without a formal guideline (Tankelevičiene & Damaševičius, 2009, p. 135). The application of automatically calculated metrics within the evaluation approach can guide the rating and, therefore, the quality assessment of ontological representations and offers an objective foundation for the interpretation of fitness for a given task. Metrics can support the evaluation of ontological representations. The propagation of metrics was the main driver for the development of the first GUI tool "OntoMetrics" (Lantow, 2016). To widen the usage of ontology metrics, we extended the OntoMetrics web tool with a RESTful-API. We want to enable a smooth integration of metrics for future applications by allowing users to consume ontology metrics in a convenient, service-driven model.

The rest of the paper is structured as follows: Section 2 illustrates the landscape of cloud-driven ontology services. In Section 3, we present the current usage scenarios and challenges regarding the use of ontologies and ontology evaluation of Robert Bosch GmbH. Section 4 is concerned with the capabilities and architecture of OntoMetrics, followed by the conclusion and an outlook on future research with the newly developed API.

2 RELATED WORK

Over the past years, various ontology evaluation tools were developed, ranging from manual procedures to semiautomated and fully automated approaches. This related work section focusses on the latter – software that allow the calculation of metrics without human involvement.

The developed automatic evaluation tools focus on different aspects like coupling, structure, coverage or correctness and differ in their integration approaches, ranging from web- or application-based standalone tools (examples are OntoMetrics (Lantow, 2016) or OntoQA (Tartir et al., 2005)) to such integrated with larger development suites (examples are Swoop (Kalyanpur et al., 2006) or Protégé (Musen, 2015)). However, a lot of the software developed is no longer available or heavily outdated. To the best of our knowledge, there is currently just one tool available with similar functionality, developed by the Universidad de Murcia[5]. While their OQuaRE based approach allows the direct calculation of statistical relevant correlations and clusters within the datapoints, it has less functionality regarding the variety of different measurements and also does not provide class-specific metrics (Franco et al., 2020). Table 1 gives some examples without raising a claim to completeness.

Table 1: Ontology evaluation tools.

Software	Category	Availability
Swoop (Kalyanpur et al., 2006)	Web Ontology-Editor	Last Update from 2007
OntoQA (Tartir et al., 2005)	Standalone Evaluation Tool	Last update from 2010
OntoMetrics (Lantow, 2016)	Web Evaluation Tool	Available and Usable
Protégé (Musen, 2015)	Ontology Editor	Available and Usable
ODEval (Corcho et al., 2004)	Standalone Evaluation Tool	Not available
OntoKBEval (Qing Lu & Volker Haarslev, 2006)	Standalone Evaluation Tool	Not available
OntoKeeper (Amith et al., 2019)	Web-Tool	Not publicly available
OQuaRE Metrics Calculation (Franco et al., 2020)	Web-Tool & Rest Service	Available and Usable

This sets up the motivation for our research: We strongly believe that ontologies will play an important role in the future, providing a structured representation of knowledge for the integration within artificial intelligence. At the same time, most ontology evaluation tools are no longer available or outdated. Rostock University still offers a functioning web-based evaluation tool, which led to the collaboration with the Robert Bosch GmbH. Having insights in the usage scenarios of ontologies and the need for evaluating and measuring ontologies in such a large corporation, we argue that as much as the usage of ontologies has changed from expert knowledge representation to a versatile tool in the

[5] http://sele.inf.um.es/ontology-metrics/

toolbox of AI, the evaluation tools have to change as well.

Cloud services more and more replace or complement former on-premise applications in almost all areas of IT, including semantic technologies, as they offer highly sophisticated technologies and infrastructure as a service, thus allowing the usage of these artifacts without the need for investments in expertise and hardware. There are already adaptions of ontological services for the cloud: Flahive et al. proposed extracting and replacing methodologies for tailoring sub-ontologies out of large domain ontologies using cloud services (Flahive et al., 2013). WebProtégé is a popular cloud-based editor for collaborative ontology modeling (Tudorache et al., 2013). Poveda-Villalón et al. developed the OntOlogy Pitfall Scanner (OOPS) for detecting anomalies within ontologies. The service is available through a GUI and a RESTful interface (Poveda-Villalón et al., 2014). VoCol is a git-based version control system, including validation, querying, analytics, visualization, and documentation (Halilaj et al., 2016). The OQuaRE tool by (Franco et al., 2020) provides a web- and REST-interface for 19 different metrics. However, currently, there is no cloud-based ontology metrics tool with the same measurement capabilities as OntoMetric available.

3 INDUSTRIAL USE-CASE OF ROBERT BOSCH GmbH

This section motivates the need for applying metrics as enhanced quality assurance mechanisms for ontologies and knowledge graphs, from the viewpoint of the industrial partner Robert Bosch GmbH. Bosch partners with University Rostock and benefits from using OntoMetrics in multiple ways and industrial use cases, as described in the following.

Bosch is a large automotive and industrial company that is heavily investing in becoming one of the world-leading artificial intelligence (AI) companies. The Bosch Center for Artificial Intelligence (BCAI), which was founded in early 2017 and had continuously been growing since then, employs over a hundred AI experts and is the spearhead of the AI research and enablement ongoing in Bosch. During the past years, the dominant AI technologies that have been developed and deployed are data-driven, subsymbolic approaches, in particular machine learning (ML) and deep learning (DL). This is changing, and symbolic approaches, in particular ontologies and knowledge graphs, are gaining strong momentum in many enterprises, including Bosch. The demand for knowledge engineering in industrial use cases is growing rapidly, but yet, we are rather at the beginning of a potentially long rise in knowledge graphs. Gartner identified knowledge graphs to be amongst the most important innovation triggers for artificial intelligence (Brant et al., 2019), as well as amongst the most promising emerging technologies of the year 2019 (Smith & Burke, 2019), with an estimation of 5 to 10 years of continuous growth.

After long years of propagating semantic technologies, we finally see many lead architects and decision-makers understand the power of semantic technologies, which opens the doors for new industrial use cases in various domains. Furthermore, a huge potential of domain and application areas is still unexplored, yet to be discovered. We believe that there will be an even stronger demand and impact of ontologies and knowledge graphs in the industry than we have seen with ML and DL, as it does not depend on the availability of large amounts of data for training the algorithms, and as it can be applied for representing knowledge of practically any domain. But also Semantic AI or Explainable AI, currently emerging as an interdisciplinary novel AI approach from the combination of ML and knowledge representation, promises a big potential for years to come (Lecue, 2020).

The universality of ontologies and knowledge graphs make them candidates for being applied in potentially all business sectors in Bosch, ranging from Mobility Solutions, over Industrial Technology, Consumer Goods, Energy and Building Technology, up to subsidiary companies like Healthcare Solutions, and business units such as Bosch Connected Industry. We see many different application areas for standard semantic technologies and challenges that they can help resolve, such as a semantic specification of our data, systems, and factories; the interoperable integration and interpretation of heterogeneous data; the formalization and application of expert knowledge, making products and services truly smart; device interoperability in multi-vendor and cross-domain settings; formal validation of systems and products. There is already a series of success stories from past and ongoing projects in Bosch, for example, the application of knowledge graphs for searching enterprise data lakes (Schmid et al., 2019), the semantic search and reuse of autonomous driving data (Henson et al., 2019), formal model checking ontologies for the verification of autonomous driving (Kaleeswaran et al., 2019), the semantic interoperability and integration of manufacturing

(Mehdi et al., 2019) and IoT data (Svetashova et al., 2019), semantic model extensibility (Svetashova, 2018), the computerized engineering of building automation systems using knowledge graphs as integrated semantic information models (Dibowski & Massa Gray, 2020), and the application of semantic technologies for improved complaint management in commercial buildings (Massa Gray et al., 2020).

A challenge, however, is the skills and expertise required for developing good ontologies and knowledge graphs. There is a large number of qualified engineers, software architects and developers skilled in conventional database techniques and programming languages available, but ontology experts or developers with a background in semantic technologies are low in number. The continuously growing demand in enterprises cannot be met by the job market, and the few ontology experts in an enterprise cannot support all ongoing modeling tasks. That is why the development of models and ontologies often needs to be driven by domain experts or developers, who lack that expertise, with only little guidance from ontology experts. Nonetheless, to make their work efficient and successful, they need mature software tools that support them in defining good ontology models on their own. This is where ontology metrics play an important role, as they can help to assess, ensure, and improve the quality of ontologies. Ontology metrics also help in determining the best ontologies from multiple competing ones, which has become a frequent task, as more and more ontologies have been developed, published, and shared on the Internet.

We made a comprehensive study of available ontology metric approaches and solutions, both in scientific publications as well as in software tools. Since the metrics need to be available within a short time and without much human interaction (i.e., at no or little cost), we were particularly searching for metrics that can be computed automatically. That strongly limited down the available solutions to a few ontology tools that calculate and show some basic ontology metrics such as counts of classes, instances, different types of axioms, etc., e.g., Protégé and TopBraid Composer. However, that rather is an assessment in terms of quantity than quality. Academic solutions, on the contrary, either propose metrics that need time-intensive, costly assessment by human experts, or that are not available (anymore) for download or as online services. Fortunately, in OntoMetrics, we found a sophisticated online service that computes a comprehensive list of various ontology metrics at the push of a button. OntoMetrics excels all other solutions we could find in its comprehensiveness of metrics it can calculate. It is under active development, well documented, platform- and tool-independent, and the makers have been interested and supportive in enabling us to use OntoMetrics within the corporation.

Over the past years, the IT landscape has undergone a tremendous change, as IT infrastructure and software architectures have moved from desktop applications and in-house server farms to web-based UIs, cloud-based infrastructure, and in-cloud data lakes. That saves cost at the enterprise side and improves flexibility, as it enables on-demand up- and downscaling of cloud resources (storage capacity, processing power). Semantic technologies fit very well into that new landscape since IRIs, dereferencability, and the OWL import mechanism allow for distributing and storing linked information in a decentralized way. The trend in the ontology domain goes into the same direction, as several ontology tools are now available as browser-based, collaborative development environments, e.g., WebProtégé, TopBraid EDG, and VoCol.

The recent enhancement of OntoMetrics from a web-based tool, where a user specifies or uploads the ontology to be assessed in a web UI and afterward sees the results, to a standalone REST service is a perfect fit for the IT landscape of today and for Bosch. It enables other applications and services to call and connect with the offered REST APIs and enables them to trigger the metrics calculation and consume the results whenever needed. As a REST service running inside the Bosch network, we have accomplished an enterprise-wide availability of OntoMetrics, accessible, and usable from within the whole enterprise, without requiring local installations. It can be consumed from various tools, teams, and projects, independent of the operating system, programming language, or hardware being used.

4 THE OntoMetrics TOOLKIT

Lantow initially introduced the OntoMetrics platform in 2016 (Lantow, 2016) as a Java EE based web application. This section gives at first an overview of the GUI-accessible metrics engine and later presents the newly developed REST-interface.

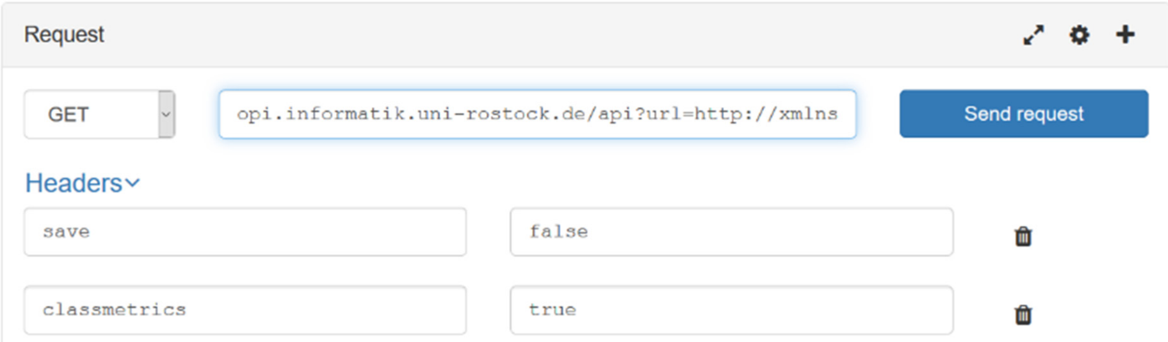

Figure 1: Accessing the OntoMetrics API through the Firefox extension “RESTED”.

4.1 OntoMetrics Web Tool

The tool OntoMetrics is publicly available at the server of Rostock University[6]. Using a simple user interface, one can paste ontology content in a textbox, a link to a web source, or upload an ontology file. The content must conform to RDF, RDF(S) or OWL and can apply a serialization via N3, turtle or RDF/XML. Overall, the metrics engine allows the calculation of 81 distinctive measurements. These metrics are mainly based on publications by (Gangemi et al., 2005) and (Tartir et al., 2005). Seventy-two of the measurements concern the ontology as a whole. They are grouped into nine categories, shown in the table below. Additionally, OntoMetrics calculates 9 class metrics for every class in the ontology, rating e.g., the connectivity or importance of a concept.

Table 2: Categories of the OntoMetrics evaluation.

Category	Meaning
Base Metrics	Simple metrics measuring the number of ontology elements *E.g. count of axioms, individuals, or object property links*
Schema Metrics	Analyses the design of the ontology *E.g. attribute richness, inheritance richness, or class-axioms ratio*
Graph Metrics	Analyses the taxonomy tree of the ontology *E.g. depth, absolute root cardinality, or average number of paths*
Knowledgebase Metrics	Analysis of individuals and ontology population *E.g. average population, class richness, or number of leaf classes*
Class Metrics	Evaluation of single classes *E.g. class readability, class inheritance richness, or class instances*

A full description of every metric, including the calculation formula, is available in the OntoMetrics wiki[7]. Before the analysis, it is possible to limit the evaluation to the categories that are needed. Especially the calculation of the Class Metrics requires a large amount of computational power. Their exclusion can significantly reduce the required calculation time.

The output prints all metrics with the corresponding category and sub-category they belong to. For further analysis in a data analysis software, it is possible to download the metrics in an XML-file.

4.2 OntoMetrics Rest-API

Cloud software, especially in a software as a service architecture, has the potential to lower the entrance barrier for new technologies. Even though the previous sections motivated the relevancy of ontologies, their integration in various use-cases as well as the need for their evaluation, simple metric applications are scarce. The new OntoMetrics API indents to fill that gap by providing an easy to use programming interface for calculating ontology metrics.

To evaluate an ontology from a web source, one can use a `GET` request on the endpoint `http://opi.informatik.uni-rostock.de/api` with the parameter `?url` pointing to the ontological resource. The full request should look like the following example for a query to the friend of a friend ontology:

```
http://opi.informatik.uni-
rostock.de/api?url=http://xmlns.com/
foaf/spec/20140114.rdf
```

[6] https://ontometrics.informatik.uni-rostock.de

[7] https://ontometrics.informatik.uni-rostock.de/wiki/

For assessing a local ontology that is not available at a web resource, it is possible to use a `POST` request on the same endpoint

```
http://opi.informatik.uni-
rostock.de/api
```

The ontology is then expected in the request body. The response is delivered in an XML serialization using the same top categories and terminology used in the GUI-version and presented in Table 2. The underlying computational engine is the same for the API, as well as for the web-application. Like in the GUI-version, the inclusion of class metrics significantly increases the response time and is therefore disabled by default. If the class-metrics are required, a header key named `classmetrics` with the value `true` enables the calculation.

If the target ontology is not consistent with an RDF syntax or one of its extensions like OWL or RDF(S), the service throws an HTTP 400 error and returns an XML consisting of further information regarding possible causes.

By default, all assessed ontologies are stored internally at Rostock University for further research purposes. This behavior can be disabled by adding the parameter `save : false` to the header. The response header contains the parameter `saved : true` if the ontology is stored on the server or `saved : false` if otherwise.

Fig 1 displays an example query to the metrics service utilizing the firefox extension "RESTED", with a declined database storage agreement and activated class metrics.

5 CONCLUSION AND OUTLOOK

Even though the semiotic based ontologies are a long-existing, mature technology compared to other AI approaches, they have not become obsolete, but in the opposite, experience much attention with an increasing amount of use cases. However, as ontology engineers are a scarce resource, these ontologies are often developed not by knowledge engineering experts, but developers within a given domain. This boldens the need for automatic evaluation of the ontological artifacts to ensure a high level of quality and comparability between the different knowledge representations.

The need for a software-based automatic evaluation has been established for several years. And over this time, various tools have been developed. Nevertheless, most of these tools are not usable anymore due to outdated data formats, deprecated dependencies, or just unavailable online resources. OntoMetrics is one of the few tools that are still available for the upcoming rise in computational ontologies. With the newly developed API, we hope to lower the entrance barrier for the use of ontology metrics. The cloud-based approach shall allow an easy integration of the measurements in semantic driven applications, thus on the one hand, further spread the use of ontology metrics, on the other hand, allow us to collect valuable data for further research.

The application scenarios of Robert Bosch GmbH highlight the need for further development and more research in the field of ontology evaluation. The extension of the OntoMetrics tool with an API is the first step to make ontology metrics more usable. The next planned feature is the integration of historical, evolutional data through the connection of a git-based repository service like GitLab or Github[8]. It is argued that through the analysis of the evolution of the measured values, statements regarding the current maturity of the research ontology can be derived.

Also, the comparing of various evolutionary progressions could allow the inferring of recommendations for the next modeling steps under the consideration of their maturity.

These are just two exemplary use-cases for the possible benefits of the analysis of historical ontology data. We think that there is a tremendous research potential in tapping these ontology repositories regarding explorative quantitative analysis, finding correlations between metrics, and deriving quality statements and recommendations.

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