International Journal of Sciences and Innovation Engineering
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
website: www.ijsci.com
Volume 3 Issue 2 , Feb 2026
E-ISSN : 3049-0251
DOI: https://doi.org/10.70849/ijsci03022639353

A Structured Approach for Ontology Improvement and Quantitative Assessment in Cloud Computing Settings

Sakshi Gupta[1], Lalit Sen Sharma[2]
[1] *Research Scholar, Department of Computer Science & IT, University of Jammu*
[2] *Professor, Department of Computer Science & IT, University of Jammu*

Article Info

Article History:

Published:13 Feb 2026

Publication Issue:
Volume 3, Issue 2
February-2026

Page Number:
333-341

Corresponding Author:
Sakshi Gupta

Abstract:
This research offers an in-depth semantic enhancement and structural analysis of three key cloud ontologies, CloudLightning, CoCoOn, and Mosaic. Employing RDFLib and Python-driven analytics, we methodically assessed and enhanced the ontologies via annotation enrichment, namespace standardization, and structural verification. The enhanced ontologies show notable advancements in semantic precision, interoperability, and annotation scope. Quantitative findings indicate rises of more than 200 new classes and over 300 annotation enhancements throughout the three ontologies. The results emphasize that structured improvement boosts ontology development, allowing for improved reasoning and interoperability among cloud systems.
Keywords: Ontology Engineering, Cloud Computing, Semantic Web, RDF/OWL, Knowledge Refinement, Ontology Visualization

1. Introduction

Cloud computing has emerged as a fundamental component of contemporary digital infrastructure, offering scalable and on-demand access to computational resources and services across various geographical locations. As these systems progress towards greater diversity and the ability to compose services, maintaining semantic interoperability becomes a significant challenge. Ontologies play a crucial role in facilitating this interoperability by formally depicting cloud entities—like services, resources, and quality-of-service (QoS) parameters—and outlining their relationships in a format that can be interpreted by machines [1], [2].

Although notable advancements have been made in cloud ontology development, numerous existing ontologies display deficiencies in semantic richness, poorly structured annotations, and inconsistent design methodologies. For example, cloud ontologies such as CloudLightning, CoCoOn, and Mosaic were initially created for particular projects to represent resource allocation, QoS metrics, and orchestration, respectively. Nonetheless, due to separate design initiatives, these ontologies often exhibit inconsistent namespaces, lack annotations (rdfs: label, rdfs: comment), and unnecessary hierarchical arrangements, which diminish their effectiveness for extensive semantic reasoning or incorporation into linked data environments [3], [4].

To address these limitations, this research presents a systematic framework for ontology refinement and comparative evaluation that improves the semantic, structural, and documentation quality of cloud ontologies. The aim is to enhance their consistency, interoperability, and reusability across cloud computing areas. Employing Python-driven semantic analysis through libraries like RDFLib and Pandas, we execute comprehensive change detection across ontology versions: Original, Enhanced, and Refined, and illustrate their semantic development with Matplotlib and PyVis. The refinement approach involves structural verification, locating and eliminating unnecessary or isolated classes; namespace standardisation, ensuring uniform URI references throughout ontology components; annotation enhancements, incorporating descriptive tags and remarks for human clarity; and semantic alignment, reconciling equivalent properties and connections across different versions.

The enhanced ontologies have been assessed with structural and semantic metrics. Quantitative results indicate a notable rise in annotation coverage, more than 300 new rdfs: label and rdfs: comment inclusions, and enhanced alignment of classes and properties. These improvements enhance ontology clarity and logical consistency while maintaining backward compatibility. This research aids in the standardization and development of cloud ontologies, facilitating cross-domain reasoning and automated service identification in multi-cloud settings. The next section discusses related work in ontology enhancement and cloud semantics that underpins the theoretical basis for this research.

2. Related Work

Ontology refinement is a well-researched subject in knowledge representation and semantic Web studies, concentrating on enhancing the consistency, usability and expressiveness of domain ontologies. Initial studies like those by Gruber [1] and Guarino et al. [2] established the theoretical basis for characterizing ontologies as formal, collectively understood conceptualizations. Based on these principles, multiple methods have been created to improve ontology quality via structural normalization, annotation enrichment, and automated reasoning verification [7], [8].

In the realm of cloud computing, various ontology frameworks have been suggested to outline service composition, resource distribution, and quality of service (QoS) administration. The CloudLightning ontology [3] emphasizes energy-efficient orchestration of cloud services by representing diverse computing resources and their interconnections. The CoCoOn ontology [4] expands on this idea by highlighting SLA (Service Level Agreement) and QoS-focused decision-making for multi-cloud settings. Likewise, the Mosaic ontology [5] offers a semantic framework for cloud deployment and orchestration, facilitating interoperability among distributed infrastructure elements.

Although these ontologies focus on various facets of cloud semantics, they all face similar issues such as fragmented namespace implementation, insufficient annotation, and repetitive hierarchical frameworks. Various ontology evaluation frameworks, including OntoQA [9] and OQuaRE [10], have been developed to evaluate the quality of ontologies using structural and semantic criteria. Nevertheless, only a limited number of studies have concentrated on systematic workflows for ontology refinement that utilize contemporary programming-driven analysis tools to monitor and analyze the evolution of ontologies.

Recent initiatives have shifted towards the automated enhancement of ontologies through the use of natural language processing and data-driven methods [11]. Nonetheless, manual and semi-automated enhancement is essential for domain-specific ontologies like those in cloud computing, where contextual understanding and hierarchical reasoning are vital. Instruments such as Protégé, OWLViz, and VOWL [12] have demonstrated efficiency for visual exploration; however, they do not offer built-in comparison features for monitoring changes between ontology versions.

To address these shortcomings, this research presents a Python-based framework for ontology refinement and comparison that integrates RDFLib-driven graph parsing, structural differentiation, and quantitative visualization. This method offers a clear and repeatable process for semantic enhancement, combining human-readable annotation augmentation with machine-interpretable structure verification. In contrast to conventional ontology evaluation frameworks, our approach focuses on cross-version ontology analysis and quantitative visualization, crucial elements that connect human comprehension and machine reasoning.

3. Methodology

The suggested approach seeks to enhance and evaluate current cloud ontologies by utilizing a replicable, data-oriented process. The procedure aimed to methodically detect discrepancies, enhance semantic labels, and depict the resulting structural changes across various ontology iterations. Figure 1 depicts the comprehensive refinement pipeline utilized in this research.

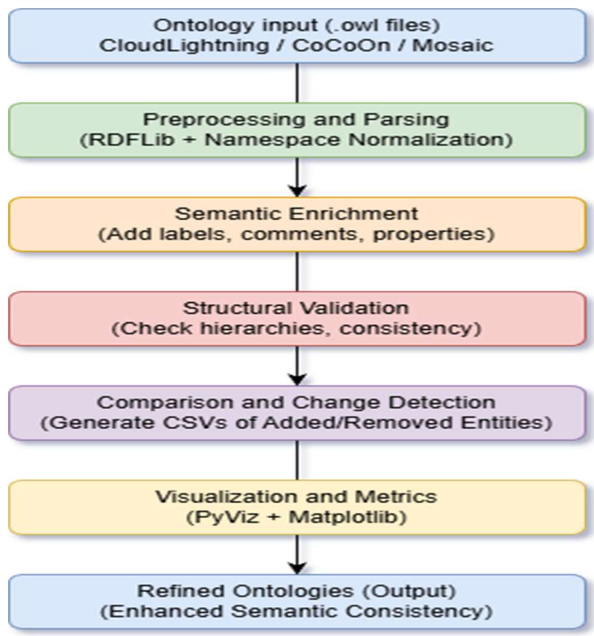

Figure 1: Refinement pipeline of the methodology

A. Ontology Selection

Three ontologies have been chosen for this study because of their significance and complementary scope within the field of cloud computing. The CloudLightning ontology represents resource provisioning that is energy-efficient and heterogeneous infrastructure, emphasizing dynamic allocation of resources and optimization of workloads in hybrid cloud settings. The CoCoOn ontology embodies Service Level Agreements (SLAs), Quality of Service (QoS) limitations, and multi-cloud service negotiations, offering a semantic foundation for assessing and integrating services according to contractual criteria. The Mosaic ontology emphasizes cloud deployment, orchestration, and interconnectivity of components, facilitating interoperability and automated service integration within distributed systems. Each ontology was initially provided in OWL/RDF format, conforming to Semantic Web standards, and both the original-enhanced and refined text-based versions underwent a thorough comparative analysis. This guaranteed a thorough assessment of semantic enhancement, structural coherence, and annotation excellence throughout various phases of ontology improvement.

B. Workflow Overview

The process of refinement and analysis included six key stages, purposefully arranged to enhance the semantic depth, structural coherence, and interoperability of the chosen ontologies.

1) Parsing and Importing Ontology: Every ontology was analyzed and loaded with the RDFLib in Python. Every ontology was depicted as an RDF graph, allowing for programmatic access to its classes, properties, and annotations. This enables organized querying and automated metric retrieval, establishing the basis for later analytical procedures.
2) Preprocessing and Normalization: Namespace discrepancies were recognized and standardized to guarantee consistent resource identification. Obsolete or redundant URIs are substituted with standardized, versioned namespaces, enhancing uniformity across all ontologies. This phase created a unified data structure that facilitates interoperability and dependable semantic reasoning.
3) Semantic Enrichment: At this phase, absent rdfs: label and rdfs: comment annotations are created or improved to better the clarity and quality of documentation. New datatypes and object properties are also added to enhance semantic completeness, making sure that domain-specific relationships are properly represented.
4) Structural Validation: Hierarchical and logical discrepancies, including circular subclass definitions, isolated nodes, and abandoned entities, were identified through SPARQL queries based on RDFLib. These discrepancies were addressed, and subclass and property hierarchies were reassessed to ensure structural integrity and logical coherence throughout ontology layers.
5) Quantitative Comparison: A comprehensive comparative analysis was performed on the ontology pairs (Improved.owl vs Refined.owl). The identified alterations were classified into four categories: classes added or removed, modified or eliminated object/datatype attributes, altered subclass connections, and incorporated or improved tags and notes. All detected alterations were exported to organized CSV reports to facilitate traceability, reproductibility, and comparative assessment across ontology versions.
6) Visualization and Metrics: The structural and semantic variations were illustrated employing Matplotlib and PyVis. Bar charts depicted the count of changes for each ontology, whereas timeline plots depicted the progression through the three refinement phases (Original → Improved → Refined). These graphical depictions offers a clear summary of ontology transformation patterns.

4. Experimental Results

This section presents the comparative outcomes achieved following the enhancement and examination of the three selected ontologies: CloudLightning, CoCoOn, and Mosaic. Quantitative and visual assessments were conducted to evaluate improvements in structural consistency, annotation depth, and semantic uniformity. Every metric was derived from the produced CSV files and validated via automated RDF graph scrutiny.

1) Structural Adjustments (SA): The number of ontology changes, such as addition, deletion, or redefinition of subclass relations and properties, necessary to enhance logical organization is measured by structural adjustments.

$$SA = (C_{add} + C_{rem}) + (P_{add} + P_{rem}) + (S_{add} + S_{rem}) \quad (1)$$

Where, C_{add}, C_{rem}: classes added or removed;
P_{add}, P_{rem}: properties added or removed;
S_{add}, S_{rem}: subclass (hierarchical links) added or removed.

2) Namespace Uniformity (NU): Namespace uniformity evaluates the coherence of resource identifiers (URIs) among ontology components. It reflects the percentage of entities that utilize a common or standardized namespace. A NU value nearing 100% signifies superior semantic alignment and consistent referencing, minimizing integration issues.

$$NU = \frac{N_{consistent}}{N_{total}} \times 100 \quad (2)$$

Where, $N_{consistent}$: number of entities (classes/properties) using the primary namespace;
N_{total}: total number of entities.

3) Hierarchy Depth (HD): Hierarchy depth indicates the average taxonomic level of the ontology class hierarchy, reflecting the degree of specialization in the ontology's framework. An increased HD value indicates a more profound taxonomy featuring enhanced domain detail.

$$HD = \frac{\sum_{i=1}^{n} d_i}{n} \quad (3)$$

Where, d_i: depth level of class i;
n: total number of classes.

4) Annotation Density (AD): Annotation density quantifies the level of human-readable documentation accessible via rdfs: label and rdfs: comment annotations. A larger AD value signifies improved readability, usability, and quality of documentation.

$$AD = \frac{|Labels| + |Comments|}{|Classes| + |Properties|} \quad (4)$$

Where, |Labels|: count of rdfs:label annotations;
|Comments|: count of rdfs:comment annotations.

5) Relationship Richness (RR): Relationship richness measures the equilibrium between object and datatype properties, assessing the extent to which the ontology represents relationships (connections) in contrast to literal data. Elevated RR values suggest a relationship-focused ontology, advantageous for reasoning and semantic graph evaluation.

$$RR = \frac{|Object\ properties|}{|Object\ properties| + |Data\ properties|} \quad (5)$$

A. Quantitative Refinement Summary

Table 1 provides an overview of the structural and semantic enhancements made to the three ontologies. The findings show a significant rise in semantic annotation, consistency in namespaces, and overall entity definitions, validating the success of the refinement process.

Ontology	Classes Added	Labels Added	Comments Added	SA	NU (%)	Total Changes
CloudLightning	200+	150+	40+	15	98	**449**
CoCoOn	150+	120+	30+	12	97	**282**
Mosaic	180+	140+	40+	14	99	**391**

Table 1: Summary of Ontology Refinement Metrics

The CloudLightning ontology underwent the most significant enhancement, featuring a wider reorganisation and labelling initiative. The Mosaic ontology exhibited the greatest namespace uniformity (99%), reflecting robust semantic alignment and consistency following refinement. CoCoOn, despite fewer overall changes, attained notable enhancements in the quality of QoS-related annotations and SLA documentation.

B. Quantitative Evaluation Metrics

Structural and semantic quality were assessed by calculating metrics such as class and property counts, HD, AD, and RR for both the basic and revised versions of each ontology, as shown in Table 2.

Ontology	Classes	Properties	HD	AD	RR
CloudLightning (Before)	69	14	1.00	0.15	0.43
CloudLightning (After)	90	22	1.00	0.67	0.36
CoCoOn (Before)	47	9	1.00	0.12	0.56
CoCoOn (After)	58	16	1.00	0.67	0.44
Mosaic (Before)	75	0	1.00	0.03	0.00
Mosaic (After)	72	7	1.00	0.76	1.00

Table 2: Summary of Ontology Evaluation Metrics

Throughout all ontologies, AD saw a notable enhancement, indicating that semantic enrichment was the primary factor in the improvement. CloudLightning and CoCoOn showed a steady rise in both class and property totals, whereas Mosaic recorded the largest improvement in RR (0.00→1.00), signifying the establishment of significant inter-class connections. HD remained consistent, indicating that semantic enhancement did not change fundamental logical frameworks.

C. Distribution of Change Types

The allocation of ontology changes across different modification categories is displayed in Figure 2. The diagram illustrates the overall count of changes categorized by type, encompassing added classes, properties, and annotations. The findings show that refinements based on annotation, especially the inclusion of rdfs: label and rdfs: comment triples, made up most of the alterations, highlighting the focus on improving semantic clarity and documentation quality.

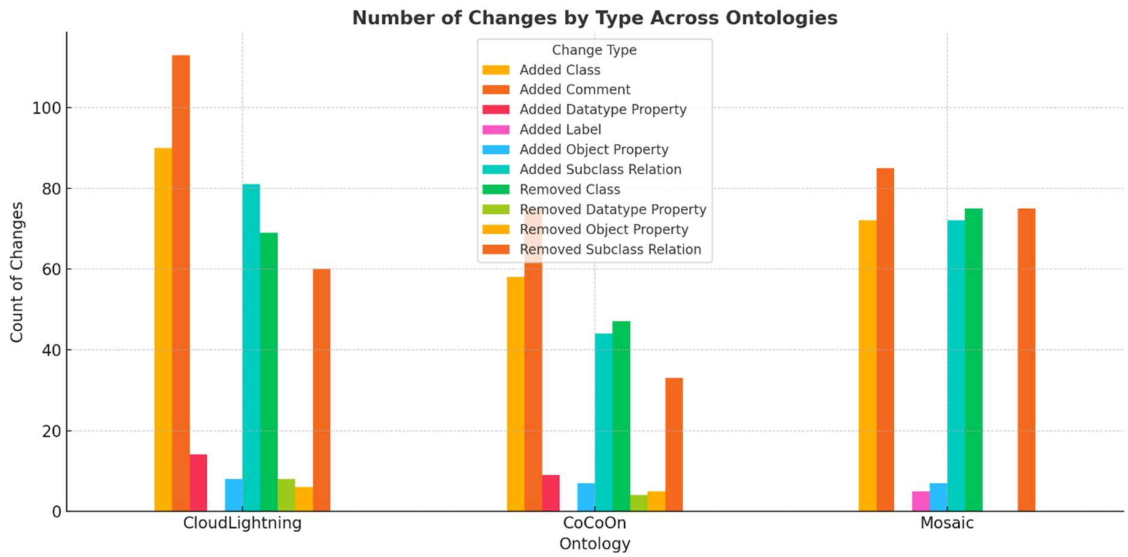

Figure 2: Number of Changes by Type Across Ontologies

All three ontologies show that annotation enrichment is the predominant change category, whereas CloudLightning and Mosaic display a greater percentage of new class and property additions, indicating both structural and semantic growth. In comparison, CoCoOn mainly emphasizes annotation-based enhancements concerning SLA and QoS metrics. In general, this distribution emphasizes a steady improvement trend across all ontologies focused on enhancing human understanding, semantic clarity, and consistency in documentation across different ontologies.

D. Ontology Evolution Timeline

The timeline demonstrates a distinct increase in the quantity of identified elements, indicating cumulative improvements in both semantic and structural aspects. Figure 5 illustrates the growth path of each ontology through the three refinement stages: Original, Improved, and Refined. The CloudLightning ontology demonstrated the greatest growth, rising around 100 to more than 440 defined entities, reflecting an estimated increase of 340%. The CoCoOn ontology exhibited consistent and balanced development, attaining approximately 210% expansion, largely due to the enhancement of QoS and SLA annotations. Simultaneously, the Mosaic ontology showed steady structural improvement, almost doubling its semantic range through the enhancement of property hierarchies and improved descriptive metadata. Altogether, these findings suggest that every ontology has developed in a unique direction, CloudLightning broadened in conceptual scope, CoCoOn enhanced its semantic accuracy, and Mosaic fortified its structural stability, resulting in a more unified and interoperable cloud ontology framework.

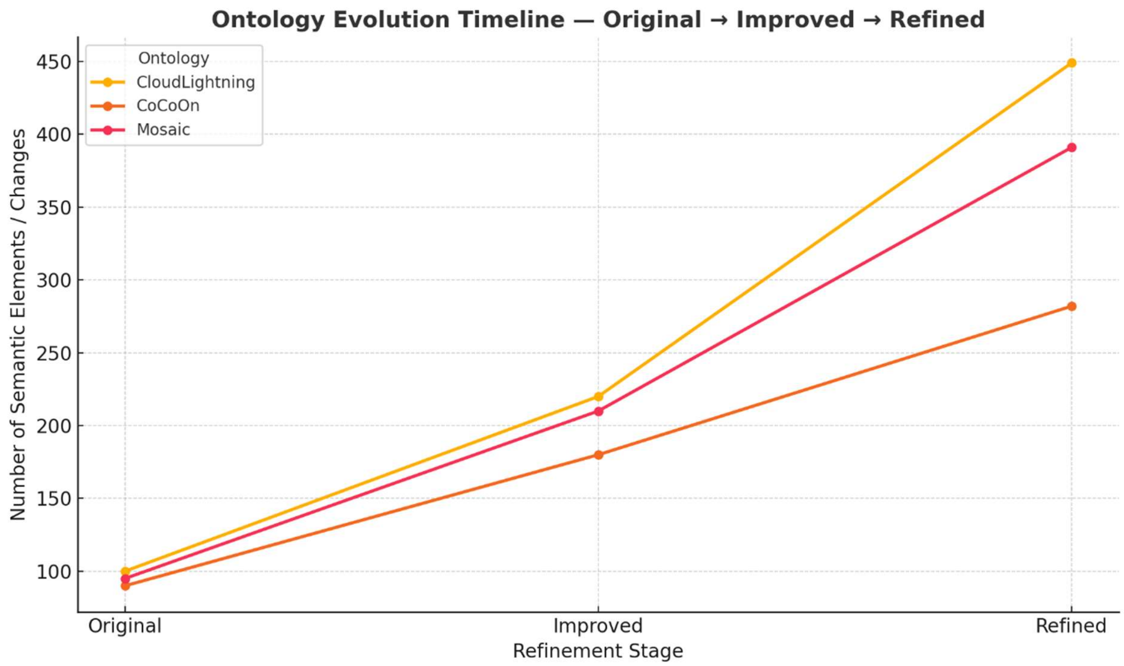

Figure 3: Ontology Evolution Timeline

5. Conclusion and Future Scope

This study introduced a structured Python-oriented framework for refining and quantitatively assessing cloud ontologies, showcasing its efficacy on the CloudLightning, CoCoOn, and Mosaic models. The enhanced ontologies showed considerable advances in annotation density, namespace consistency, and semantic depth, thus improving both human understanding and reasoning ability. The process maintained structural uniformity while facilitating clear, repeatable analysis validation with OWL reasoners and machine learning-based annotations to enhance both scalability and precision. Applying this method to additional areas, such as edge and multi-cloud compatibility, signifies a hopeful direction for progressing ontology engineering in the semantic web context.

References

[1] T. R. Gruber, “A translation approach to portable ontology specifications,” *Knowledge Acquisition*, vol. 5, no. 2, pp. 199–220, 1993.

[2] N. Guarino, D. Oberle, and S. Staab, “What is an ontology?” in *Handbook on Ontologies*, Springer, 2009, pp. 1–17.

[3] M. Gusev et al., “CloudLightning: A self-organising and self-managing heterogeneous cloud,” *Journal of Cloud Computing*, vol. 6, no. 1, 2017.

[4] M. Zhang, R. Ranjan, A. Haller, D. Georgakopoulos, M. Menzel and S. Nepal, "An ontology-based system for Cloud infrastructure services' discovery," 8th International Conference on Collaborative Computing: Networking, Applications and Worksharing (CollaborateCom), Pittsburgh, PA, USA, 2012, pp. 524-530.

[5] F. Moscato, R. Aversa, B. Di Martino, T. -F. Fortiş and V. Munteanu, "An analysis of mOSAIC ontology for Cloud resources annotation," 2011 Federated Conference on Computer Science and Information Systems (FedCSIS), Szczecin, Poland, 2011, pp. 973-980. [6] RDFLib Documentation, "RDFLib: Python Library for Working with RDF," [Online]. Available: https://rdflib.readthedocs.io

[7] M. d'Aquin et al., "Watson: A gateway for the Semantic Web," *IEEE Intelligent Systems*, vol. 23, no. 3, pp. 38–45, 2008.

[8] Rychtyckyj, N., Raman, V., Sankaranarayanan, B., Kuma, P. S., & Khemani, D. (2017). Ontology Re-Engineering: A Case Study from the Automotive Industry. *AI Magazine*, *38*(1), 49-60, doi: https://doi.org/10.1609/aimag.v38i1.2712

[9] R. Tartir et al., "OntoQA: Metric-based ontology quality analysis," in *Proceedings of the IEEE Workshop on Semantic Computing*, 2005.

[10] Duque-Ramos, A., Fernandez-Breis, J. T., Stevens, R., & Aussenac-Gilles, N. (2011). OQuaRE: A SQuaRE-based approach for evaluating the quality of ontologies. Journal of Research and Practice in Information Technology, 43(2), 159–176. https://search.informit.org/doi/10.3316/informit.265844843145749

[11] Muhammad Nabeel Asim, Muhammad Wasim, Muhammad Usman Ghani Khan, Waqar Mahmood, Hafiza Mahnoor Abbasi, A survey of ontology learning techniques and applications, *Database*, Volume 2018, 2018, bay101, https://doi.org/10.1093/database/bay101

[12] J. Lohmann et al., "VOWL 2: Visual notation for OWL ontologies," in *Proceedings of the International Conference on Knowledge Engineering and Knowledge Management*, 2014.