Leveraging Cloud Computing for the Semantic Web: Review and Trends

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Abstract

Semantic and Cloud Computing technologies have become vital elements for developing and deploying solutions across diverse fields in computing. While they are independent of each other, they can be integrated in diverse ways for developing solutions and this has been significantly explored in recent times. With the migration of web-based data and applications to cloud platforms and the evolution of the web itself from a social, web 2.0 to a semantic, web 3.0 comes the convergence of both technologies. While several concepts and implementations have been provided regarding interactions between the two technologies from existing research, without an explicit classification of the modes of interaction, it can be quite challenging to articulate the interaction modes, hence building upon them can be a very daunting task. Hence, this research identifies and describes the modes of interaction between them. Furthermore, a "cloud-driven" interaction mode which focuses on fully maximising cloud computing characteristics and benefits for driving the semantic web is described; providing an approach for evolving the semantic web and delivering automated semantic annotation on a large-scale to web applications.

Keywords Cloud Computing, Semantic Technologies, Semantic Web, Semantic Annotation, Cloud-Driven, Semantic Cloud

1 Introduction

Semantic Technologies and Cloud Computing are two major areas in Information Technology providing solutions to different challenges. However, they both interact in diverse ways and for specific purposes. With the diversity in their modes of interaction, it has become pertinent to identify and define the different interaction modes. A research work by Adedugbe et al (2017) focused on the review and analysis of semantic annotation presenting a case for leveraging cloud computing paradigm to address some of its challenges. The work is taken further by analysing the different modes of interaction of semantic technologies and cloud computing, critically reviewing existing work in each area. It then focuses specifically on how cloud computing can facilitate the semantic web and enhance some of its capabilities. The current web comprises mostly of documents that are only understandable by humans; lacking the appropriate elements to foster understanding by computers. This is due to the lack of context awareness for web documents. The semantic web is built on technologies that focus on enabling computers understand web documents by defining context for them using structured annotation data derived from knowledge graphs (Wu et al., 2017). Hence, the semantic web constitutes an extension of the current web and comprises of contextual data in such a way that it can be understood and processed by machines. The semantic web concept was initiated by Tim Berners Lee who also invented several web technologies, standardised by the World Wide Web Consortium (W3C).

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On the other hand, cloud computing paradigm offers several capabilities for IT solutions across diverse industry sectors such as education, health, finance and governance. It combines features from earlier paradigms alongside its own native features; positioning it as possibly the most effective computing paradigm to date (Mell and Grance, 2011). Furthermore, it provides capabilities for reducing the complexity of information technology (IT) management and delivering the promise of utility computing. Building on virtualisation technologies, cloud computing transforms the traditional capital-intensive model of IT into a set of easily configurable, manageable and scalable services that may be purchased as needed (Mateen and Waheed, 2016), representing "both the applications delivered as services and the software and hardware systems within the data centres which provide such services" (Brandis et al., 2014). It also provides customers with on-demand services (Fang et al., 2015) and facilitates rapid provisioning of computing applications (Rittinghouse and Ransome, 2017). The benefits relating to cloud computing include rapid elasticity, rapid provisioning, scalability, lower costs, greater resilience, fast deployment and ubiquitous network access. Despite the progress made with the semantic web, several issues such as scalability, storage, knowledge extraction and sentiment analysis continue to deter its evolvement (Buscaldi et al., 2018). This suggests that only little content is available on the semantic web with the need to facilitate context-awareness for web documents at large through semantic annotations towards a fully semantic web. While diverse technological innovations such as Cloud Computing, Fog Computing and Internet of Things continue to evolve, little has been done towards how any of these can be leveraged for the semantic web. Hence, this research investigates leveraging cloud computing paradigm for the semantic web and more specifically, semantic annotation with focus on an automated system for providing semantic annotation as a service.

The remaining sections of the paper is structured as follows: Section 2.0 provides an overview of semantic technologies and its different set of standards, with focus on how they impact the web. Section 3.0 describes the convergence of both technologies; with a summary review of existing research efforts within the domain. Section 3.1 describes a semantic cloud; whereby semantic technologies are deployed to provide solutions that enhance cloud platforms in diverse ways. Section 3.2 focuses on cloud-based semantic applications, which describes hosting semantic-based applications in the cloud and leveraging cloud computing technological artefacts to enhance their efficiency levels. Section 3.3 features cloud-driven semantic applications, as defined by this research, which is based on efforts to leverage cloud computing beyond merely hosting applications in the cloud. Section 4.0 defines a 'cloud-driven' approach for large-scale automated semantic annotation on the web. This approach is believed to possess potentials for fully maximising cloud computing benefits based on the paradigm's characteristics. Section 5.0 provides a conclusion for the paper, followed by references.

2 Semantic Technologies

The phrase "semantic technologies" refers to a set of programming languages and standards with common exchange protocols and data formats to support a web of data across several domains (Coronado et al., 2015). As its name suggests, semantic technologies employ formal semantics to provide context for digital documents. The semantic web is the focus for implementing semantic technologies, and it refers to a web where documents and data are contextual using ontologies and semantic graph databases for the provision of annotation data for web documents. The semantic annotation of web documents also implies that machines can understand and process these documents, thereby increasing the effective and efficient use of documents on the web (Berlanga et al., 2015).

Furthermore, the semantic web fosters expression of content not only using natural language, but by other means that provide comprehension, interpretation and usability abilities to software agents (Ye et al., 2015). This makes finding, sharing and aggregating information from multiple sources easier, laying groundwork for the evolution of what is called "The Data Web" - the publishing of structured data records to the web for remote reusability and querying (Khalili et al., 2016). With a semantic web, data integration and interoperability of applications achieves a new level; providing interlinked open access to data and creating the path towards a its full evolution (Verspoor et al., 2015). As a result, web documents can become context-aware, using annotation data for various processing and management capabilities, facilitated by intelligent agents (Rudman and Bruwer, 2016). These intelligent agents are software programs designed to enable the collection of information according to user's interaction on the web, in order to perform automated tasks for users. This is facilitated by scientific languages offering information description that machines, and intelligent agents can understand (Ye et al., 2015).

The semantic web concept can also be described as involving the provision of a general framework that adds a semantic layer to the web for facilitating and allowing machines to read, understand and interpret web content (Bourgonje et al., 2016; Gutierrez et al., 2019). The aim of this is to enable data sharing and reuse across diverse applications and systems; converting structured and semi-structured web documents into a 'web of data' that allows expression of basic semantics in a way machines can process and understand (Ye et al., 2015). The machine-readable data can be produced through the creation of schema comprising of marked and interlinked characteristics such as defined terms, properties and formal relationships of web documents (Gutierrez et al., 2019). Furthermore, the creation of such schema creates the need for a semantic structure and the representation of statements collected in a formal set of relationships known as ontology (Akgun and Ayvaz, 2018). Ontologies provide definition for the rules of representation and the establishment of relationship hierarchies (Narula et al., 2018). This allows for the contextualisation of data points by linked data through the supply of additional information on data, thereby enabling comprehension of information by machines (Halford et al., 2013). Several technologies play a role in facilitating the semantic web in diverse ways. While some are generic to information systems, others are quite specific for the semantic web. Figure 1 presents the semantic web technology stack.

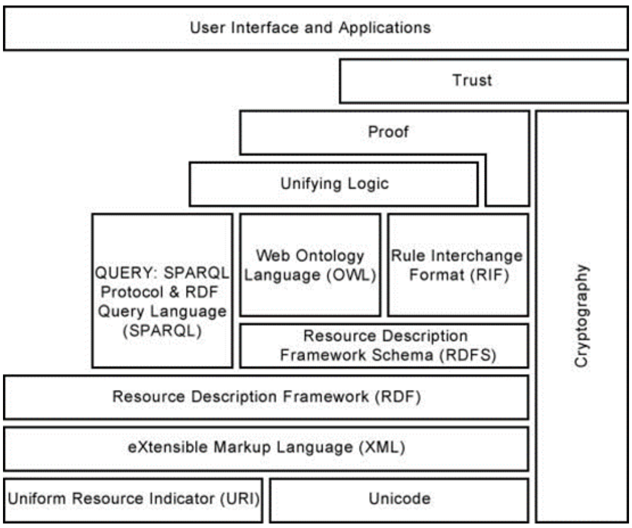

Fig. 1 The Semantic Web Technology Stack (W3C, 2017)

A wide range of technologies and standards constitute the semantic web technology stack as represented in Figure 1. These are utilised for varying functionalities across the implementation of a semantic web and can be described as follows:

- The Unicode and URI Layer define standards for recognising semantic web objects and validating the use of international character sets for data representation (Alam et al., 2015).
- The XML (eXtensible Markup Language) Layer which also comprises of namespaces and XML Schema helps in integrating semantic web and XML-based standards. XML is responsible for the provision of surface syntax applicable to structured documents without imposing semantic constraints on what the documents stand for (Ye et al., 2015).

XML Schema focuses on the schema for XML documents; defining a strict structure for elements contained within them.

- RDF is a simple data model for referring to objects and their relationships. It facilitates the portability of annotation data across multiple platforms. XML and RDF technologies complement each other in building an intelligent web (Gutierrez et al., 2019). The RDF (Resource Description Framework) layer alongside RDFS (Resource Description Framework Schema) and RDFa (Resource Description Framework with attributes) facilitates the schematic and syntactic definition of vocabularies to be referenced by Uniform Resource Identifiers (Ye et al., 2015). The resources, semantic relations, links and services are also defined in this layer. It makes provision for a directed graph formalisation, with nodes representing resources and arcs representing properties.
- RDFS represents a vocabulary to describe properties and classes of RDF resources, including semantics for generalisation-hierarchies of such properties and classes at various abstraction levels (Ye et al., 2015).
- The Ontology Layer is based on the description of concepts, properties and relations within ontologies. It also outlines traits between various concepts which helps in vocabulary evolution (Basu, 2019, Wang et al., 2015). OWL (Web Ontology Language) is a prominent standard on this layer and it offers description of roles for ontological components and their inter-relationships.
- RIF (Rule Interchange Format) is for rule exchanges within the web while SPARQL is a recursive acronym for Sparkle Protocol and RDF Query Language and is used to query semantic graph databases for data in formats such as RDF or JSON (Ye et al., 2015).
- The Cryptography Layer ensures data security by means of encryption across the different standards available within the semantic web stack (Alam et al., 2015).
- The Unifying Logic Layer authors rules for the semantic web while the Proof Layer implements them. The Trust Layer collaborates with the Proof Layer to evaluate application mechanism and validate the implementation of rules (Alam et al., 2015).

3 The Convergence

While cloud computing is about the delivery of IT (information technology) facilities; both software and hardware as a service, semantic technologies provide a means for computers to understand data from a human point of view and process them accordingly. As a result, cloud computing and semantic technologies have a reciprocal relationship with semantic technologies providing an approach to integrate the different application components of an information system and to manage their interactions from a contextual point of view. This interaction facilitates the integration of new applications within IT systems and their lifecycle management. With respect to the semantic web, automation is key to its evolvement considering the high level of dynamism and expansive size of the web. With automation being very central to cloud computing, it could be leveraged for the required automation on the semantic web to deliver semantic annotation. Furthermore, web documents and data are generally being migrated to cloud platforms due to benefits inherent in adopting cloud computing such as better insights and visibility, collaboration, supporting diverse business needs, allowing for rapid development and provisioning of new products and services through automated systems (Namasudra et al., 2017). The need for very high level of computer processing power for data storage, processing and management is also a factor that supports having integrated solutions based on both technologies. With the vast amount of data on the web and its ever-increasing nature, coupled with the generation of equally large amounts of annotation data, high performance computing would be required to effectively store, process and manage the entire data and their lifecycle. Cloud Computing offers this level of high performance and can be leveraged for the same purpose (Husain et al., 2011). Likewise, the need for delivering semantic annotation as a service (SaaS), via a platform (PaaS), on an infrastructure (IaaS) for web documents is crucial. These are models which cloud computing offers (Mell and Grance, 2011). In addition, the need to automate the processes of deploying (rapid provisioning), scaling (dynamic scalability) and monitoring (usage monitoring) processes on the semantic web provides a basis for the integration.

Based on these, the modes of interaction between them are identified and detailed in this section. This was done by carrying out a literature review of research efforts within both domains. The review identified, appraised and synthesised all the empirical evidence that meets pre-specified eligibility criteria to answer given research questions. The major focus was on finding out the feasibility of cloud computing paradigm being a solution for driving the semantic web, in terms of providing a platform for the delivery of semantic annotation on a large-scale to web applications. From the literature review conducted, three major interaction areas were observed between the two technologies. These are (i) semantic technologies within application domains hosted on a cloud platform, (ii) development and deployment of one or more semantic technologies for a cloud platform; known as semantic cloud and (iii) the use of a cloud platform to facilitate an application built with one or more semantic technologies. The distribution of relevant publications across the three interaction areas is presented in Table 1 and subsequent sections (3.1 to 3.3) analyse each interaction mode as defined in the table.

Table 1 Classification of interaction modes between semantic technologies and cloud computing

Classifications	Sub-Classifications	Publications
Semantic Technologies for Cloud (Semantic Cloud)	**Cloud Interoperability and Portability**	Di Martino and Esposito (2016), Di Martino et al. (2013), Rezaei et al. (2014), Malki and Benslimane (2013), Sheth and Ranabahu (2010), Somasundaram et al. (2012), Challita et al. (2018)
	Discovery, Selection and Utilisation of Cloud Services	Xu et al. (2016), Brandis et al. (2014), Kang et al. (2011), Dautov et al. (2013), Takabi (2013), Tan et al. (2010), Rodríguez-García et al. (2014), Kim et al. (2010), Liu et al. (2014), Veloudis and Paraskakis (2016), Riazuelo et al. (2015), Santana-Perez et al. (2017), Giakoumis et al. (2015), Cortazar et al. (2012), Manno et al. (2012), Cretella and Di Martino (2012), Nelson and Uma (2012), Alti et al. (2015), Hua et al. (2019), Pileggi et al. (2013), Modi and Garg (2019), Trajanov et al. (2012), Castane et al. (2018)
	Cloud Security	Bernabe et al. (2014), Hu et al. (2012), Auxilia and Raja (2012), Pham et al. (2018), Zhang et al. (2015)
	Description of Cloud Resources and Services	Fang et al. (2015), Ahn and Kim (2015), Souza et al. (2015), Benton et al. (2011), Bhattacharyya et al. (2016), Bassiliades et al. (2017), Hamadache (2014), Di Martino et al. (2017), Ward and Barker (2012)
Semantic Technologies in Cloud (Cloud-Based Semantic Applications)	**SaaS Layer**	Gezer and Bergweiler (2017), Di Modica and Tomarchio (2016), Kourtesis et al. (2014), Yang (2015), Xia et al. (2014), Pendyala and Holliday (2010), Fu et al. (2018), Tao et al. (2013), Rani et al. (2015), Park et al. (2014), Benkner et al. (2014), Zhang (2015), Yuan et al. (2008), Amato et al. (2015), Gracia and Mena (2011), Fensel (2011)
	PaaS Layer	Santana-Pérez and Pérez-Hern'ndez (2012)
	IaaS Layer	Di Martino et al. (2017)
Cloud Computing for Semantic Applications (Cloud-Driven Semantic Applications)	**Standard**	Mika and Tummarello (2008), Corradi et al. (2016), Hsu and Cheng (2015), Husain et al. (2011), Dessi et al. (2016)

3.1 Semantic Technologies for Cloud

Several semantic technologies and solutions have been implemented for cloud platforms, making them semantic in nature. A semantic cloud fosters the efficiency of a cloud platform with respect to services across the different delivery models (IaaS, PaaS and SaaS). This is usually implemented using semantic technologies such as RDF to model data for cloud services and OWL or RDFS to develop ontologies for cloud models. Currently, ontologies exist for providing metadata for cloud entities' description. However, most of these still require further enhancement and enrichment (Nawaz et al., 2019). From the review of existing literature on semantic cloud, a classification for the utilisation of semantic technologies for cloud platforms is presented and evaluated as follows.

3.1.1 Cloud Interoperability and Portability

While interoperability between applications at the software-as-a-service level in cloud computing presents challenges, semantic technologies have increasingly been used to address them and overcome some of the barriers. The work by Yongsiriwit et al. (2016) asserted that semantic technologies are the fundamental prerequisites towards achieving interoperability in the cloud. The implementation of semantic interoperability frameworks is critical for software-as-service systems within the cloud. In addition, semantic technologies are used to provide comprehensive service specification across various abstraction levels and service categories. For instance, Fang et al. (2016) proposed a fuzziness-embedded and agility-oriented semantic model that captures cloud interactions and details across different abstraction levels including SaaS, PaaS and IaaS. The model can be used to reveal multiple agile interactions among the resources and services within a cloud computing environment. Figure 2 presents the agility-oriented ontology design of the work by Fang et al. (2016).

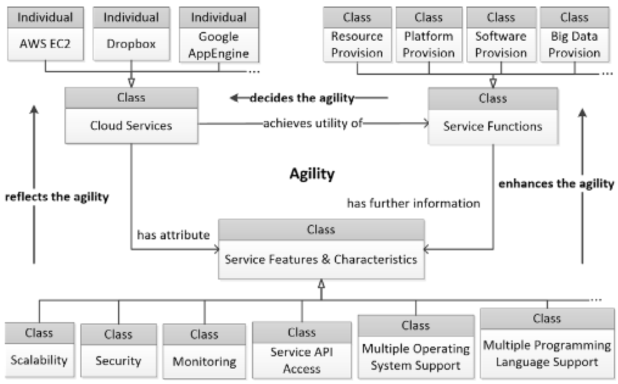

Fig. 2 Agility-Oriented Semantic Model for Cloud Services (Fang et al., 2016)

In addition to enhancing interoperability of cloud-based applications and inter-cloud policies, semantic technologies are also critical in resource scheduling and provisioning within an inter-cloud environment. Particularly, ontology-based resource description helps in solving inter-cloud interoperability problems making it possible for proper resource provisioning from different cloud service providers. The work by Di Martino and Esposito (2016) proposed an Inter-Cloud Resource Provisioning System (IRPS) that allows for semantic description of tasks and resources. The system also facilitates storage of such tasks and resources using resource ontology which in turn facilitates proper resource allocation based on a semantic scheduler and inference rules. Similarly, Challita et al. (2018) developed an OCCI (Open Cloud Computing Interface)-based cloud formal language aimed at the problem of interoperability between heterogenous, multi-clouds. The framework provides semantic-based specifications for the three major cloud delivery models as well as across diverse cloud computing issues. Overall, semantic technologies have been observed to be critical in solving inter-cloud interoperability issues, enhancing scheduling and provisioning success rate, increasing cloud resources' efficiency and enhancing the throughput of cloud-based applications.

3.1.2 Discovery, Selection and Utilisation of Cloud Services

Another important application of semantic technologies in the cloud is in their use for the discovery, selection and utilisation of cloud services (Rekik et al., 2015). One of such uses is to enhance topic coherence. Without the use of semantic technologies such as RDFS, OWL and SPARQL, it is difficult to discern whether a set of annotation data is related to a topic. Considering this, a cloud transformation model was developed by Zhang et al. (2015) which not only determines the relationship between annotation data and a topic but also integrates annotation data into the necessary topic model. This model enhances performance and reduces noise while integrating semantic knowledge into Tag-LDA model. Furthermore, semantic technologies have proven to be vital for testing reproducibility of scientific experiments. The reproducibility of results obtained from scientific experiments is regarded as the cornerstone of any scientific method (Zhang et al., 2015). Unlike conventional techniques for addressing reproducibility, semantic tools provide scientists with a platform for sharing and capturing valuable knowledge regarding computational experiments', enabling them to capture the execution environment under which such experiments are performed and share them through the cloud. Specifically, Santana-Perez et al. (2017) proposed a novel approach that describes scientific workflows' execution in the cloud using semantic vocabularies.

In addition, the work by Alti et al. (2015) proposed a multi-level ontology-based architecture referred to as OntoSmart which can be used to enhance "the high level of context concepts abstraction for heterogeneous service sources and profiles using a top-level ontology". This architecture is beneficial to overcoming the barrier resulting from the heterogeneity and diversity of cloud-based service sources and profiles. In addition, semantic technologies are critical in making the cloud more scalable so that it can interconnect a vast number of servers while supporting a variety of online services within the cloud environment. This is observable from the work by Hua et al. (2019) which presented a scalable and distributed data-centric system referred to as "Antelope" for cloud computing data centres. The system can be used to overcome the possibility of mismatching between data placement and network architecture, taking into consideration the data placement's optimisation as well as the network architecture's property. Its underlying concept is leveraging the precomputation-based data cube to enhance online services hosted in cloud platforms.

Furthermore, semantic technologies enhance the capabilities of cloud-based platforms in terms of management and knowledge representation, bridging semantic resources together in distributed cloud-based platforms and fostering the interconnection of cloud-based heterogeneous services (Pileggi et al., 2013). They are also critical in enhancing service access and discovery within cloud environments. The work by Modi and Garg (2019) proposed a QoS-based approach that utilises cloud computing ontology for semantic discovery, selection and composition of cloud-based services. Additionally, they help in the integration of cloud services among different cloud-based platforms. Trajanov et al. (2012) proposed a framework referred to as "Semantic Sky" as a platform that allows the integration of many cloud-based services via semantic technologies. This system is capable of automatically discovering user's cloud context and offering the necessary actions which can be executed with data within the context. It also automates the process of executing users' tasks, resulting in improvements to users' efficiency, information exchange and productivity. Similarly, Castane et al. (2018) proposed a semantically enabled architecture for managing heterogenous resources within a multi-cloud environment; delivering high-performance computing and optimising cloud resources utilisation. The architecture leverages mOSAIC ontology and extends it to foster self-management of services within the cloud.

3.1.3 Cloud Security

Semantic-based approaches have also been deployed to enhance security mechanisms within a cloud environment. Privacy and security concerns have made organisations reluctant to shift their respective business operations to the cloud (Veloudis and Paraskakis, 2016). Hendre and Joshi (2015) also stated that cloud providers are required to adhere to necessary privacy and security policies towards ensuring users' data are kept secure and confidential. Their research led to the development of a semantics-enabled application that allows cloud users to identify necessary cloud compliance and policy statements required for their organisations. The application also facilitates the identification of privacy and security threats within a cloud computing environment and the compliance and security models against such threats.

Semantic technologies are also used for retrieving encrypted data from cloud environments. Yang (2015) emphasised the vital role encryption plays in protecting privacy and security of data before and after transfer to a cloud platform. As such, semantic technologies are used to overcome the limitations of traditional data retrieval methods such as keyword search. The work by Fu et al. (2018) further stated that there are various searchable encryption techniques for performing searches on secure outsourced data. Pham et al. (2018) also proposed an architecture for delivering a secure search technique as a solution to the problem of searching over encrypted data in the cloud. Similarly, Attribute-Based Encryption (ABE) schemes enhance the flexibility of accessing confidential data as well as the ease of sharing such data, as illustrated in Figure 3 which presents a search model of encrypted data in cloud.

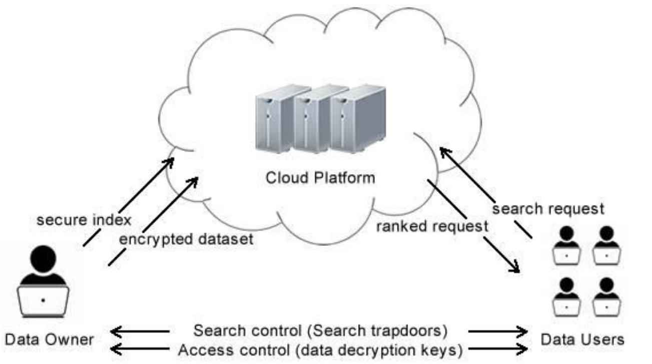

Fig. 3 A search model over encrypted data in cloud. (Zhang et al., 2015)

3.1.4 Description of Cloud Resources and Services

Contextual description of resources and services in the cloud greatly enhances their effective use. One of the uses of semantic technologies for cloud is the monitoring of systems. Ward and Barker (2012) proposed "a scalable distributed data collection system" as a tool for monitoring cloud systems at the infrastructure as a service level. This monitoring includes server resources utilisation levels such as processing power consumption, disc storage usage, etc. Data collected from the monitoring is used to provide appropriate, real-time statistical status for cloud resources. The system is based on RDF rather than flat files or relational databases. Chernyshov et al. (2016) defined RDF as a straightforward way of describing instance data in the subject-object relation using resource identifiers. The RDF's vocabulary is extensible through other schemas that facilitate the generation of comprehensive ontologies to represent a problem domain. Unlike other non-semantic enabled cloud monitoring tools that utilises flat files or relational databases, Ward and Barker's (2012) proposed system employs RDF which provides storage for all machine-readable information, providing a means for computers to be able to understand and process the data accordingly.

3.2 Cloud-Based Semantic Applications

Several semantic applications have been developed and deployed to run from a cloud platform. There has been an extensive implementation and usage of semantic technologies for different services delivery over the cloud. These utilise technologies from the semantic web stack, such as RDF, RDFS, OIL (Ontology Interchange Language) and OWL (Web Ontology Language). Such services benefit from computational cloud resources, which is vital given that cloud computing provides high performance computational resources for data and applications, thereby enhancing ease of access and economic savings (Rittinghouse and Ransome, 2017). Cloud computing has attained unprecedented development in industry and academia due to its ability to relieve the burden of data management and data security (Zhang, 2015). As such, semantic-driven applications have become increasingly deployed in the cloud. Furthermore, cloud computing provides platforms of massive storage and data management. Specific systems based on cloud computing aim to improve functionalities like storage, editing, recovery and creation of data. An example is the research effort by Gezer and Bergweiler (2017) which focused on the use of semantic technologies to implement a cloud-based application for describing, managing and executing scientific workflows for experiments. The semantic technologies act as a recommendation system; providing service suggestions for workflow execution.

Likewise, Amato et al. (2015) proposed a system that leverages semantic web technologies for document composition such as editing or composing aiding services; exploiting hardware and software functionalities (service model) provided by the cloud service provider. The system can be applicable to various domains, but the testing of the system was streamlined to the health domain. The paper proposed CloSe, a cloud software as a service system for document semantic composition. CloSe depicts a development in the cloud computing domain for record handling and is dependent on semantic methodologies. The framework exploits data and information contained in suitable document bases, gathered from heterogeneous sources, for appropriate recommended fragments to be embedded in the document. The outcome demonstrated that the framework improves the archive structure; helping and providing preliminary results about the viability of the semantic recovery methods, in view of precision, recall and f-measure metrics. However, performance assessments of the framework were not revealed.

One major challenge with application development is the high cost of infrastructure deployment. Semantic web application development can take advantage of cloud infrastructure that guarantees scalability, flexibility and easy maintenance. Cloud computing offers a better alternative to on-premise solutions. Semantic web applications can be based on two types of cloud technologies; firstly, horizontal cloud services which provide a platform functionality that creates a conducive environment for developers to build semantic applications and deploy them on the platform as a Service (PaaS) layer. Secondly, vertical cloud services which gives tenants the ability to acquire a service as an application itself where the semantic applications can operate in the cloud and provide services directly to the customer. This service is on the Software as a Service (SaaS) layer. PaaS on the other hand, can facilitate various functionalities for the SaaS layer in this case; such as semantic data management as a service, semantic search as a service, data integration as a service and NLP (Natural Language Processing) as a service (Fensel, 2011).

Currently, there are several examples of semantic applications running as a service. An example is the development of Virtuoso RDF databases and their provision on a virtual machine copy for the Amazon EC2. This database is then distributed as Virtuoso Cloud Edition. OpenLink Data

Spaces (ODS) is another semantic application on a cloud platform. It provides a distributed web application platform that helps in the creation of points that indicate web presence for exposing, exchanging and creating data. This application also runs in Amazon's EC2 Cloud (Fensel, 2011). Also, the Talis Platform is a cloud-based application used by developers for data storage. This application stores both structured and unstructured data and provides a platform for managing and manipulating them (Gracia and Mena, 2011). These semantic web applications hosted on the cloud and provided as a service indicate how vital cloud computing can be for running semantic-driven applications.

3.3 Cloud-Driven Semantic Applications

The cloud-driven concept defines application development that requires a cloud environment for deployment; providing a medium to fully leverage cloud computing paradigm. This is opposed to hosting applications which can run from a traditional computing environment in the cloud. While some approaches can be observed from research, they exhibit varying degrees to leveraging cloud computing, hence, raising the question of how to fully leverage the paradigm. The research by Mika and Tummarello (2008) considered web semantics in the cloud, providing an overview of semantic web technologies and three various aspects that have to do with semantic web technologies in the cloud. Firstly, cloud computing for web data was discussed; these web data includes metadata obtained from applications that run on the web and computational data produced via search engines. Due to the large amount of data generated from the web, the use of cloud services was proposed as an effective way of handling these data. Technologies such as MapReduce and Hadoop were considered for processing these large datasets. Secondly, the use of Yahoo! Pig to process huge amounts of RDF data was discussed. An overview of Yahoo! Pig for querying large volumes of information in a batch processing mode utilising clusters of several machines, without evident challenges in scalability was analysed. Throughout the examination it was seen that Yahoo! Pig's information model and change language are like the relational representations of RDF and the SPARQL query language. The authors stretched out Pig for processing RDF queries. A limitation of using the model was highlighted as it provides solutions for only the offline batch processing task. The author recommends that more algorithms be included into the MapReduce framework to address the issue of scalability. The scope of the research is also supported by Kim et al. (2010) with a proposition for e-portfolio designs based on a private-public data index system that integrates cloud computing applications and storage with semantic web architecture.

Similarly, Husain et al. (2011) addressed the issue of complex queries and scalability for large semantic web data. Leveraging cloud technologies, a scalable semantic framework was built to handle queries regarding RDF dataset which was becoming very large and complex. The reason for this work was because the authors stated that the existing solutions that has been provided, though they handle large RDF dataset, they are usually not scalable, or they do not scale adequately. The authors devised a novel algorithm to handle complex queries, that is queries with optional blocks which their previous work did not include and basic graph queries. Hadoop framework was also utilised to store the RDF data and MapReduce was used for the query answering system, although some algorithms were used for modification to achieve scalability. The system was tested using SP2B dataset and the desired result was achieved. The article did not dwell much on the performance of the queries when applied to larger datasets. However, the system was stated to possess capabilities for maintaining scalability and efficiency in such cases.

Furthermore, Hsu and Cheng (2015) proposed a cloud service model called Semantic Agent as a Service (SAaaS) which involves the integration of a semantic web and software agents as a typical approach to access cloud resources consistently. SAaaS was developed using UML but it was enhanced to use SAUML; Semantic-based Agent UML. The proposed model was associated with an existing cloud service to encourage the improvement of resourceful cloud computing applications. In line with this, the work by Dessi et al. (2016) proposed the use of semantic web technologies in relation to bioinformatics. The authors discussed the concerns of technologies been suitable for promoting the prerequisites of a cooperative environment where a research community share and develop information regarding the biomedicine discipline. The authors proposed COWB (Collaborative Workspaces in Biomedicine), a system which underpins collective knowledge management with regards to biomedical communities to address this issue. The framework was a cloud service model based on PaaS (Platform as a Service), displaying an elective method to knowledge management and utilising cloud platform to share information aggregately. It also enabled storage of knowledge bases across several machines and accessible to a wide range of users.

Corradi et al. (2016) also towed the Platform as a Service (PaaS) model, proposing a mobile cloud infrastructure for extracting semantic data from speech recognition within social care domains. The system proposed was MoSSCa, a mobile cloud empowered speech recognition system that provides semantic-enhanced text recognition, which is challenging on cell phones without a portable, supporting cloud architecture. The study did exhibit a system and an architecture, with a survey across various accents, queries and high levels of concurrent user requests. The architecture aided the processing and management of vast amounts of information in a Big Data environment. Across different research efforts within this mode, it can be observed that diverse solutions have been deployed within a cloud platform to provide higher productivity levels based on the high-performance nature of cloud computing paradigm. However, such solutions can also be hosted within traditional computing environments with little or no architectural or structural changes. This defines a significant difference to solutions for deployment in the cloud; designed and developed to be driven by the principles of cloud computing paradigm which subsequently enables them to fully maximise the paradigm's benefits.

4.0 Cloud-Driven Semantic Web

This is based on developing a semantic web application that is well-suited for maximising cloud computing benefits by deploying a development process which ensures cloud computing characteristics and benefits are fully maximised. According to Gilbert (2018), the key to maximising cloud computing benefits for software applications does not lie with the cloud infrastructure alone, but also with the architecture of software deployed in the cloud. This opinion is elaborated on by Leymann et al. (2016). The basis of the opinion focuses on the development of applications utilising a software architectural pattern that enables the decomposition of an application into loosely coupled but highly cohesive modules such that each module is independently deployable, scalable and updateable; which are features central to the fundamental principles of microservices software architecture. With the microservices architecture, it implies that automatic scaling is at the level of each microservice rather than scaling an entire application due to the auto-scaling needs of a single module, thereby making judicious use of computing resources and limiting the computational overhead. In addition, adopting the microservices software architecture provides faster 'time to market' for applications and software products by speeding up processing time as separate development teams can work on different microservices of the same application in parallel (Taibi et al., 2017). In addition, Dragoni et al. (2017) opines that most organisations today use microservices to become more agile in responding to market changes. With the ability to leverage both hypervisor-level and operating system-level virtualisation for applications and deploy them on a cloud platform, supported by a software integration that is fully automated, the speed of implementing new software features is greatly increased. Figure 4 illustrates a microservices application, embracing polyglot programming whereby each microservice has its own development technology stack.

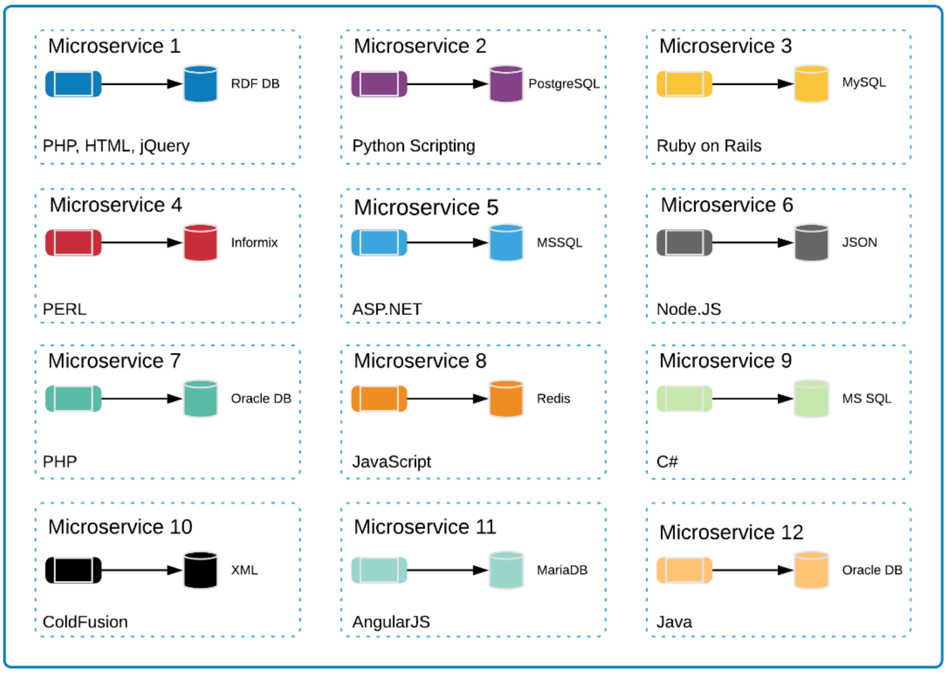

Fig. 4 Microservices Software Architecture with Polyglot Programming

Leymann et al. (2016) further provides an approach for leveraging cloud computing generally using containerised open-source software stacks such that the development process assigns every part of an application its own container to ensure each part is dynamically orchestrated. This implies having containerised microservices, leveraging both hypervisor-level and operating system-level virtualisations (also referred to as containerisation) and an orchestration platform to deploy them. However, even though it fosters such potential benefits for applications in the cloud, the automation of application lifecycle by means of a continuous integration and delivery is very vital for a solution requiring the level of dynamism, agility and efficiency as semantic annotation for web documents. A continuous integration mechanism for application lifecycle automation for large-scale semantic annotation would be required to avoid several potential bottlenecks that can arise as a result of the ever-dynamic nature of the web.

A continuous integration mechanism refers to the ability of delivering an automated and continuous stream of updates to a software based on a workflow. Such updates can be as often as possible; including several times daily. Container Orchestration Engines such as Kubernetes and Docker Swarm can facilitate this by an integration with third-party solutions for the purpose (Garg and Garg, 2019). Updates for software to ensure and maintain the required level of accuracy and consistency between components of a semantic annotation solution such as ontologies, RDF graph databases, web documents and annotation data requires an automated means that will facilitate the persistent nature of such updates. Based on these, the following features are defined for the cloud-driven mode of semantic annotation, which is further illustrated with Figure 5.

- Development of modularised functionalities for a semantic annotation process using microservices architecture.
- Encapsulation of the modularised semantic annotation functionalities in software containers (otherwise referred to as Containerisation) for operating system-level virtualisation using container software such as Dockers.
- Configuration of the containerised functionalities for both hypervisor-level and operating system-level virtualisation.
- Orchestration for automating deployment, scaling, monitoring and management of the containerised functionalities using container orchestration software such as Kubernetes, Docker Swarm or Amazon Elastic Container Service, among others.
- Application Automation Lifecycle for continuous integration and delivery using a continuous integration mechanism.

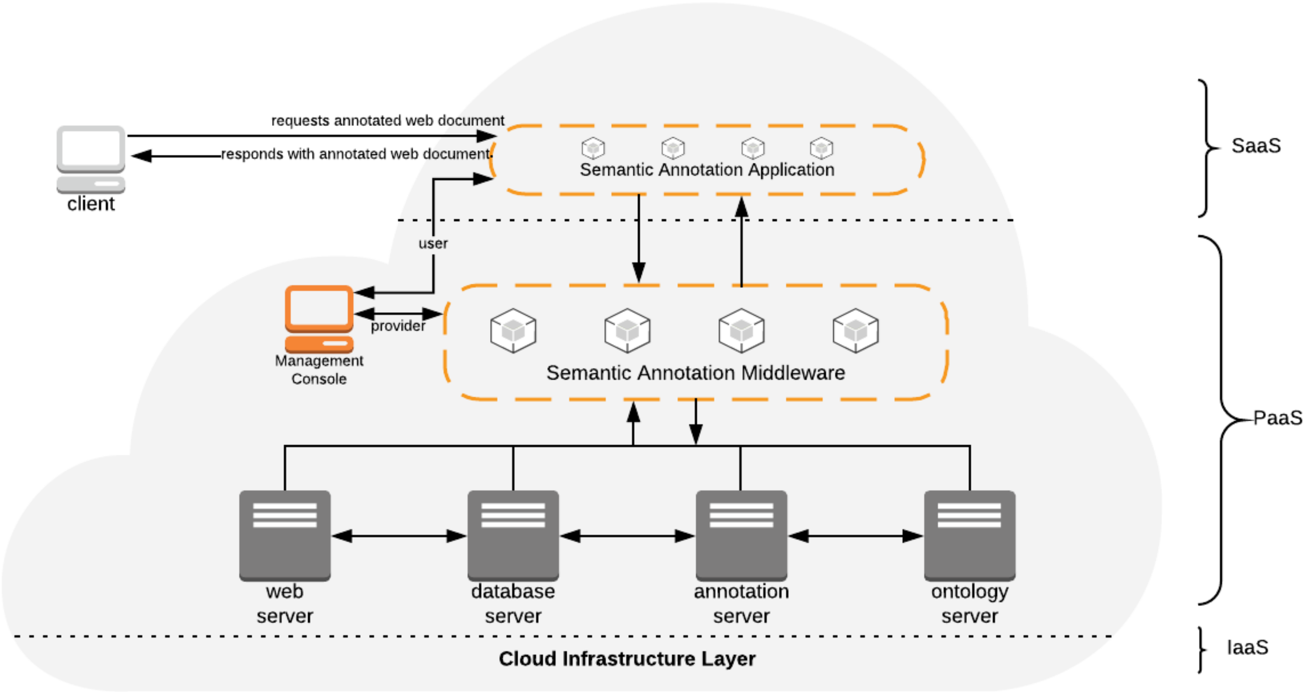

Fig. 5 High-Level Cloud-Driven Semantic Annotation

With focus on the management of annotation data lifecycle, the high-level framework described in Figure 5 would foster capabilities such as the following for the semantic web.

4.1 Annotation Data Storage

Refers to the storage mechanism of contextual data for annotating a web document. These can be domiciled within the web document which is classified as a monolithic approach or they can be stored separately from the web document, known as a decoupled approach (Uren et al., 2006). For web-scale semantic annotation, the decoupled approach is believed to be more efficient and effective for their intended purposes. Table 2 presents a comparison of these two approaches.

Table 2 Comparison of Monolithic and Decoupled Annotation Data Storage Mechanisms

Monolithic Annotation Data Storage	**Decoupled Annotation Data Storage**
It does not foster collaboration	It promotes collaboration
Changes in web document automatically makes the annotation data invalid.	Changes in a web document automatically triggers a re-generation of annotation data for the document.
Annotation data is not sharable among multiple web documents.	Annotation data can be shared by multiple web documents
Annotation data is usable only by the web document it is embedded in.	Annotation data is re-usable by multiple web documents
Requires a 1:1 mapping for web documents and annotation data	Fosters a 1: N mapping for web documents and annotation data
Annotation data is always available with the web document	Annotation data and web document exist separately
Annotation data can be edited locally, which can lead to errors	Annotation data is not locally available for editing; hence its integrity is preserved.

With the dynamic nature of the web, web documents and ontologies are frequently evolving and requiring updates. The decoupled approach will facilitate automatic updating of annotation data; triggered when either corresponding web documents or ontologies change as a result of an update to content, context or structure. Considering the structure of annotation data which can be in portable formats such as XML, JSON or YAML, changes within a web document would require a re-generation of its annotation data which needs to be an automated process without a user's direct access to the annotation data. However, with the monolithic approach, annotation data is exposed to users, hence the chances of changes to it by non-experts which will subsequently render the web document semantic annotation invalid. A scheduled server script such as cron jobs on Linux kernels can be set up to monitor web documents evolution and initiate annotation data re-generation when such documents evolve.

4.2 Annotation On-the-fly

Refers to the ability of a semantic annotation process to provide online, real time and automated semantic annotation for web documents. Upon the receipt of a request by a web server for a web document, annotation data can be generated for the web document content by running SPARQL queries on a semantic graph database for contextual data regarding the web document. The generated data; which is annotation data is then stored as well as referenced by the web document instantaneously. This is based on a typical client-server architecture for web applications on the Internet. A service-based model which web documents can subscribe to for such a level of automation is not known of to the best of the writer's knowledge and is believed to constitute a major stride towards the successful evolvement of the semantic web. Such a service would require a high level of automation to enable non-experts utilise it; possibly by means of an API (Application Programming Interface) call within web documents.

Furthermore, considering the wide-scale use of web content management systems and frameworks which can utilise a single header file for multiple web documents (hundreds or even thousands), the API call would only be needed once within a header file and that would facilitate semantic annotation for all the web documents. In addition, considering this capability alongside Annotation Data Storage; web content editors, web administrators and several other categories of non-technical web content managers can have full and free access to web content without any chances of altering annotation data content or structure.

4.3 Annotation Data Reuse

The adoption of a decoupled approach to annotation data storage means it can be re-used by one or more web documents. Annotation data remains valid if the web document content remains the same. Hence, the same instance of annotation data can be served to a web document multiple times without requiring a re-generation of the data if the web document has not changed. This provides a means of optimising computing resources usage, especially considering that some web documents do not change frequently. A mechanism for facilitating the requirement would involve mapping web document URLs to annotation data IDs within a database such that once a web server receives request for a web document, a record in the database table assigning annotation data to the web document is checked for. The assigned annotation data would then be reused for the document if such a record exist. Otherwise, annotation data is generated for the document real time.

4.4 Annotation Data Sharing

Annotation data generated for a web document and stored on an annotation server can be shared with other similar web documents of the same domain and containing similar content. This will foster optimisation for the usage of computing resources as it means the same annotation data is not replicated across a server multiple times for different web documents, thereby consuming more storage and requiring increased processing power to access them. Furthermore, an update to the annotation data is immediately implemented for all web documents referencing it, providing a cascading effect over multiple web documents all at once. Access to an instance of annotation data for sharing can be managed based on consumer or document attributes using an attribute store for entities. Entities in the context will be annotation data, web documents and users. With Attribute-Based Access Control (ABAC), annotation data attributes are signed to security tokens which matches them with document or consumer attributes to either grant or deny access to an instance of annotation data (Talukdar et al., 2017). However, this is still based on the validity of a web document utilising an instance of annotation data previously generated for another document.

4.5 Annotation Data Auto-Update

The dynamicity of annotation data is very crucial due to the ever-changing nature of web documents (Saravanan and Radhakrishnan, 2018). Annotation data once generated, would require a re-generation whenever either the web document or domain-specific ontologies generating the annotation data is updated. This is to ensure that consistency is maintained within the three components; web documents, annotation data and domain-specific ontologies. Updates to the annotation data are implemented by queries sent to both the web server (containing web documents) and ontology server (containing the ontologies) from the annotation server. The response from either of the servers determine if an update is required for the annotation data. Annotation data can be stored using XML or JSON which are portable and interoperable formats usable on the web for storage and data transfer across different platforms (Malik et al., 2018). With the decoupled approach to annotation data storage, which stores annotation data separately from web documents, it is pertinent to ensure that an up-to-date annotation data is always served to web documents, hence this process focuses on automatically updating annotation data when required. Scheduled tasks can be set to iteratively select web document URLs from a database and read their contents. If there have been any chances to a web document content from the previous running instance of the scheduled job, then annotation data for the specific document would have to be regenerated. The regeneration would require invoking some other processes; Ontology Selection, Ontology Mapping and Annotation Data Storage.

4.6 Annotation Data Optimisation

As the structure of ontologies evolve over time, structural changes might be required for corresponding annotation data. With annotation data stored in formats such as XML, JSON or YAML which are highly structured document types, optimising the structure of annotation data in order to keep the integrity of the contextual information it stores is perceived as a needed requirement. While Annotation Data Auto-Update is about updating annotation data itself, Annotation Data Optimisation is about optimising the structure of annotation data documents, which invariably may result in minor changes to the actual contextual data stored in it. This will also constitute a form of maintaining consistency between ontologies and annotation data by eliminating any disparities between them, which is very vital for the accuracy of contextual information within annotation data files. The optimisation process would need to be automated and scheduled to be run for annotation data when its supporting ontology or one of its multiple supporting ontologies has gone through a structural change due to an upgrade or evolvement.

4.7 Annotation Data Colocation

With the decoupled approach to annotation data storage which is based on storing annotation data separately from web documents, the co-location of both becomes a factor of interest. Annotation Data Colocation defines a mechanism in which annotation data is stored as closely as possible to the corresponding web document. This is based on the technological concept of colocation which in simple terms means placing resources together, or close to each other for one or more reasons (Aiyar et al., 2018). These reasons include to foster faster communication and reduce network latencies as communication between system nodes is faster when the nodes are closer to each other than when the nodes are away from each other (Saeed et al., 2015). While the location of web documents is dependent on the document owners or authors, with a global presence for most application hosting providers, annotation data can be stored in the same geographical zone as its corresponding web document and close to it as much as possible. Alongside the benefit for web users and web document owners, it will also constitute a huge benefit for hosting solution providers by greatly minimising computing overhead for semantically annotating web documents globally. Furthermore, in cases whereby web document location can be influenced by hosting solution providers, demand and usage statistics for such documents becomes more important as these can be utilised to select the most appropriate location for web documents and their associated annotation data based on proximity to the target audience.

5 Conclusion

This paper focused on the different modes of interaction between semantic and cloud computing technologies with a view to identify potential opportunities for facilitating evolvement of the semantic web. Existing research efforts within the domain were reviewed and analysed, with two major interaction modes identified. The research further identified and defined a “cloud-driven” mode with some existing research efforts inclined towards the concept, in which cloud computing can be fully leveraged for the semantic web beyond merely hosting and running a semantic web application on a cloud platform. From the feasibility study, technical requirements were described to facilitate this, with a high-level framework of the concept. This leads to the conclusion that a semantic web application driven by the cloud, hence, fully leveraging cloud computing capabilities will provide a basis for the delivery of semantic annotation as a cloud service, with web applications subscribing to its usage. However, further research and experimental validation would be required to fully establish the concept and its performance metrics for large-scale semantic annotation of documents on the web. Finally, it is pertinent to extensively research into how annotation data can be further enriched and optimised because the availability of a cloud-driven platform for semantic annotation would need to be complemented with rich-content annotation data to obtain the best results of effectiveness and efficiency.

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