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Department of Computer Science

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# Master Thesis

Design and Implementation of a Web-Based Software for the  
OPC Unified Architecture Integrated into a Semantic Ques-  
tion Answering in the Domain of Smart Factory

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**Orcun Oruc**, Design and Implementation of a Web-Application for OPC UA Protocol Integrated into a Semantic Question Answering, Master Thesis, Department of Computer Science Chemnitz University of Technology, 11 March 2019

## **Sperrvermerk**

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## **Abstract**

Manufacturing technologies in the manufacturing systems have been shaped over the past few years. Such changes in information technology, data analysis and manufacturing systems has enabled data collection and this concept incarnated as smart factory in industrial plants.

Nowadays, a factory generates more obscured data from manufacturing process and industrial communication rarifies the connectivity between manufacturing devices. Those issues on manufacturing systems have changed their demands in terms of smart factories that aim to boost performance and productivity in manufacturing. In this context, machine-to-machine protocols have been evolved in helping to shape requirements relevant to production systems. Service-oriented architecture and compatibility to high-level client-server communication put forward the OPC Unified Architecture. OPC Unified Architecture (OPC UA) is a de-facto protocol in the usage of communication at the industrial scale of smart factories, sensor networks, and manufacturing systems. The OPC Unified Architecture supports eliminating the dependency of factory-level communication and creating a vendor-independency in smart factories.

One of the main problems affecting the smart factory is non-uniform and lack of standardization, which could examine a factory system without knowing the underlying structure. The latter is an assistant question answering that enables natural input to answer operators. Even though a smart factory generates a massive amount of data

## **ABSTRACT**

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through industrial processes, technical personnel or operators cannot easily interpret the linked data created by different sources. A semantic question answering can reply questions of the operator and experts that posed in a natural language. Those questions can consist either streaming data or static data regarding industrial communication.

To tackle those two problems as a whole, this work proposes an architecture design as well as a robust implementation in the web-based platform, which chiefly focuses ease of integration and usage. In essence, the goal of this thesis is to create an operator assistant web-based software. To achieve this goal, the research will orchestrate a particular machine-to-machine protocol and human to machine approach that serves as a web-based software.

Notably, the thesis will examine the integrated web applications relevant to OPC Unified Architecture and assess the applicability of the semantic question answering aspect of the natural language understanding.

The practical implementation of this research follows a staged approach; we then examine architectural requirements and viability of OPC Unified Architecture to the web environment; besides, we will provide results about the practicality of the semantic question answering system in terms of human-machine interaction.

Consequently, this thesis exemplifies a practical implementation to evaluate the operator assistant web-based software in smart factories. This research will be an innovative tool with significant findings for the future researches in the sense of human-machine application integration into the OPC Unified Architecture.

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**Glossary****CXXXI**



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## List of Abbreviations

|                   |  |
|-------------------|--|
| <b>NLP</b>        | Natural Language Processing                        |
| <b>HMI</b>        | Human Machine Interface                            |
| <b>REST</b>       | Representational State Transfer                    |
| <b>JSON</b>       | JavaScript Object Notation                         |
| <b>JWT</b>        | JSON Web Token                                     |
| <b>OPC UA</b>     | Open Platform Communication Unified Architecture   |
| <b>Fraunhofer</b> | Fraunhofer Institute for Machine Tools and Forming |
| <b>IWU</b>        | Technology   |
| <b>VDMA</b>       | Mechanical Engineering Industry Association        |
| <b>MVP</b>        | Minimum Viable Product                             |
| <b>RFC</b>        | Request For Comments                               |
| <b>RDF</b>        | Resource Description Framework                     |
| <b>SOA</b>        | Service Oriented Architecture                      |
| <b>OLE</b>        | Object Linking and Embedding                       |
| <b>SDK</b>        | Software Development Kit                           |
| <b>CLR</b>        | Common Language Runtime                            |
| <b>RDF</b>        | Resource Description Framework                     |
| <b>SPARQL</b>     | SPARQL Protocol and RDF Query Language             |
| <b>W3C</b>        | World Wide Web Consortium                          |

## LIST OF ABBREVIATIONS

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|            |                               |
|------------|-------------------------------|
| <b>XML</b> | Extensible Mark-up Language   |
| <b>DOM</b> | Document Object Model         |
| <b>MVC</b> | Model-View-Controller Pattern |
| <b>SDK</b> | Software Development Kit      |

# 1 Introduction

## 1.1 Motivation

"The most obvious characteristic of science is its application: the fact that, as a consequence of science, one has a power to do things. And the effect this power has had need hardly be mentioned. The whole industrial revolution would almost have been impossible without the development of science."

- Richard P. Feynman

Today, human operators and experts have too many generated data, and complex protocol structures that can be complex depends on vendors of devices and facilities in an industrial plant. Advanced manufacturing evolved with the technology called 'Industry 4.0' that enables unstructured linked data through the devices where dispatch messages with industrial communication protocols. Industrial plants and their automation processes have been digitized and equipped with sensors and actuators. Then an infancy term came to exist so-called 'Smart Factory'. Smart factories apply operations that should be able to run without much human operator's intervention. Connectedness among sensors, machines, and systems created complex communication infrastructure, beyond that the generated data by smart factories became more complicated to understand and interpret for human operators.

More specifically, information gathering through complex, unstructured data and communication architectures in a smart factory have a critical role for human operators and experts. If we ignore the problems, gathering information would be time-consuming and tedious while wading through a large number of semantic documents with semantic queries can also increase training and operation time. The process of collecting technical information may aggravate the mobility of human operators and the productivity on an assembly line or a manufacturing device.

## **1 INTRODUCTION**

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We want to design and implement web-based software to solve the problems above. This web-based application should be high performance, ease of use, robust, secure and scalable according to the needs of a smart factory. Technology considerations of the operator assistance web-based software may orchestrate with the architectural design to alleviate the problems mentioned above for human operators and experts. More importantly, it should respond to the requirements of a smart factory aspect of analytics of data.

In order to design and implement the web-based software, we should able to traverse vendor-specific platform-independent data of OPC Unified Architecture or interlinked heterogeneous data source with a user interface. Tackling the problem in the smart factory domain, we aimed to design and implementation of an operator assistance web-based software that can answer the limited type of questions related to pieces of equipment of manufacturing and traverse data among various industrial devices through OPC Unified Architecture with limited knowledge of underlying structure.

Lastly, Fraunhofer IWU continuously researches connected sensors, and actuators' data brings us a need for further understanding of the meaning of data. The semantic question answering can interpret the meaning of data, a heterogeneous data source should handle the produced data by smart factories and by the information model of OPC Unified architecture. The operator assistance web-based software orchestrates an industrial automation protocol and Natural Language Understanding, which can increase the ability of adaptive automation between human operators and manufacturing devices.

### **1.2 Problem Statement**

We want linked data of manufacturing devices can be seamlessly comprehensible by experts, with limited information about complex technical architecture, the experts should also can aware the internal process of the industrial devices utilizing natural language queries.

The problem that we faced is a necessity of an aggregated information retrieval-industrial communication suite at a smart factory of Fraunhofer IWU by utilizing the company-specific data. Current researches do not tackle the problem as a whole in industrial manufacturing. The issue that we encountered can impact that human operators or factory workers spend a considerable amount of time on operating machines by using

smart devices. When a new technical personal attends in a smart factory, the web-based software can reduce the training cost by giving general information about a particular manufacturing process of a facility.

However, the lack of technical information about industrial automation the underlying about industrial automation is a significant problem for experts who work in smart factories. Human-centered assistance application design can show error logs where the error occurred in manufacturing devices. A control module can poll instantly servers are up and running using OPC Unified Architecture. An operator can observe simulated data without installing any software from anywhere. Moreover, an expert can plan the process while look at interlinked data in the heterogeneous data source that consist of streaming data or static data.

We cover this research in the context of industrial automation at different facilities in the same smart factory of Fraunhofer IWU. After describing the necessary parts of OPC Unified Architecture and features of the question answering, we need to implement the operator assistance web-based software.

The web-based software implies that a design decision of the web-based software can change the robustness and efficiency of the web application. Not only we can think of a web-based software deploying for a single manufacturing device of a smart factory, but also we consider that a large number of users can connect to this system. Therefore, a robust and scalable design has an essential role in deploying the overall system. In case of obtaining a solution, there will be an innovative solution that can implement into a smart factory, which supports increasing the efficiency outcome at the manufacturing scale.

We will use a top-down approach to design and implement the web-based application with state-of-the-art web technologies by taking into consideration of architectural design thinking. More specifically, our methods rely on frameworks of back-end and front-end development that integrated into various libraries of natural language understanding.

### **1.3 Objectives and Scope**

The goal of this thesis is to create an architectural view that serves as an operator assistant web-based software. Particularly, the operator assistant web-based software brings

## 1 INTRODUCTION

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into together subdisciplinary concepts of the computer science so-called question answering system and OPC Unified Architecture machine-to-machine communication protocol by assessing the viability of web technologies and suitability of natural language understanding concept.

This thesis reviews the past literature to indicate the gap in knowledge and possible limitation while linking the internal data of a particular service that resides in OPC UA and orchestrating the semantic question answering. As a part of this work, we need to clarify the current state of research on scientific publications regarding important inquiries that guide clearly in a literature review. The study has two-fold research methods, which are theoretical review and practical implementation.

This research scope limited with the smart factory that is relevant to manufacturing technologies. The part of OPC Unified Architecture connectivity will be restricted with definitive services that would comply with our research questions. Due to the limitation of data scope, the semantic question answering system will answer questions regarding industrial automation.

This thesis also reviews past literature to indicate the gap in knowledge and possible limitation while creating a heterogeneous data source and linking of an OPC UA Information Model with the data source. We will have some limitations while conducting the research, which are:

The first limitation is that we will implement a module that allows querying, writing and monitoring for current data assessing the optimal web software architecture at a basic level. We are not aiming to research historical data access and alarms.

The second limitation is that data sources can be streaming key-value mapped data or generated data from OPC UA Information Model, but the sample size is relatively small for ontology-based systems. The data source does not contain documents, plain text or open linked data. A couple of data source has been created for the sake of reaching research goals. As a persistent data storage called graph databases will not be considered in this work.

The third limitation is that the manually created test questions are mandatory to evaluate for the semantic question answering.

The fourth limitation is deployment technologies such as containerization, or continuous integration technologies will be out of scope. The scope also does not include cloud-

based and serverless architectural pattern when it comes to the design of web-based software.

The scope does not cover creating a full-fledged application that browses and modify every possible data types in OPC Unified Architecture; rather, our scope covers designing of the operator assistant web-based application at the architectural level and the quantitative and qualitative evaluation. Likewise, the semantic question answering component does not address paragraph-based input and unlimited data domain with unlimited types of questions.

Last but not least, we have defined research questions to consider possible implications, and we try to answer at the end of the research. To reach the primary goal, I have set up research questions and hypotheses

These research questions and hypothesis as below:

My fundamental research question is:

- How can I design and implement an operator assistant web-based software with a web architecture that consists of semantic question answering and OPC Unified industrial communication technology in the domain of smart factory?

Important sub-questions that relevant to the part of operator assistant web-based software:

RQ 1) Are the services of OPC Unified Architecture are good enough to make and well enough to perform for a factory-wide deployment concerning industrial communication?

RQ 2) What would be the optimal web architecture aspect of robustness, security, ease of use and high performance to implement the operator assistant web-based application in a smart factory?

RQ 3) Can a semantic question answering utilize restricted domain heterogeneous linked data source (e.g., OPC UA based data, streaming data, static data) and how well perform?

RQ 4) Can we scale our approach to other smart factories or plants?

My hypotheses are the following:

- H 1) The modules of proposed architecture will not affect each other in the context of performance and functionality.
- H 2) The proposed system will provide correct and rapid results to human operators.
- H 3) Existing algorithms and design principles in the previous researches can be applied to the operator assistant web-based software.

### **1.4 Organization and Contributions**

This thesis contributes to the research circle in the following ways:

- We introduce an innovative web-based software by demonstrating a detailed architecture for realizing an assistant software that is robust, secure, performative, and ease of use. The architecture integrates web application designing, web architecture, OPC Unified Architecture industrial communication, and Natural Language Understanding.
- We propose a synthesized idea through transdisciplinary areas of computer science so-called web science, communication network and artificial intelligence to make an assistant software for human operators in a smart factory.
- We introduce a human-machine interaction tool that can be answered to factoid questions from multiple data sources such as time series data and linked data of OPC Unified Architecture.
- We introduce an industrial communication tool integrated into a semantic question answering to aware of context information in a smart factory.
- We initialize with simple architecture without load balancing and reverse proxy feature and
- We evaluate the architecture through performance and functional experiments and provide empirical results to the readers. Also, we evaluate the question answering part with manually generated questions.

This research organized as follows.

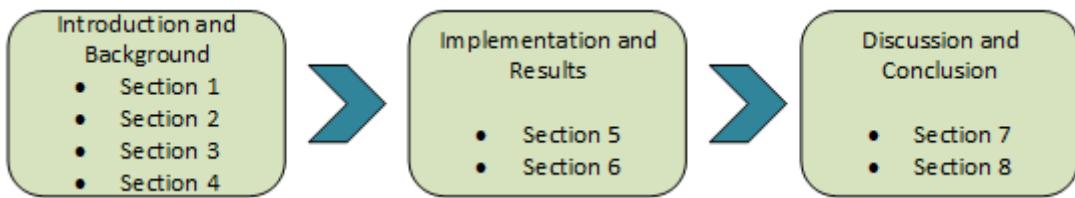


Figure 1.1: Organization of the Thesis

Section 1 presents motivation, problem definition, scope, and related works. For literature reviews of OPC UA, Question Answering and Data Preparation are examined separately.

Section 3 introduces industrial communication in smart factories in terms of theoretical background of operator assistant and human-machine interaction.

Section 4 explains the theory of the Semantic Question Answering in the context with natural language understanding.

In Section 5, we will elaborate on the details of practical implementation with architectural details.

Test preparation and results will be in Section 6, and we will list the results under the section. Before we reach a conclusion, we will comment on our results and express our results are meaning to readers in Section 7. Finally, the conclusion part will define our findings and future improvements in Section 8.

## **2 State of the Art**

We will discuss the state-of-the-art research by splitting up Section 2.1, Section 2.2, and Section 2.3. Each section will give information towards sub-questions that have mentioned previously. In the end, we will summarize the state-of-the-art researches by discussing essential points that could steer with the rest of the thesis.

### **2.1 Background of OPC Unified Architecture in Web Environment**

The following statements give brief information about the historical development process of OPC Unified Architecture. On the path of development, OLE OPC was formerly known as OLE for Process Control has been widely dispersed at the industrial scale. The term Object Linking and Embedding for Process Control traced back to initial development that was founded by Microsoft in order to communicate objects with Component Object Model (COM). Object Linking & Embedding was a collection of operating system services that allowed anyone to include component objects in an application or allow one to package component objects for use in other applications[2].

The principle of OLE is to develop modular applications that refer to a ground-breaking step for loose coupling in object-oriented programming. The use of object-oriented techniques encouraged reusability and maintainability to industrial communication. OLE has utilized component objects that can have relations with other objects. The objects that belong to the OLE Model could support interfaces to deploy an abstraction layer for other objects. The ultimate drawback of OLE components that do not support inheritance to increase the integrity of run-time development [2]. This issue led to another issue, which multiple vendors can create multiple types of objects and releases, and yet, OPC Unified Architecture development demanded to solve multiple releases issue through data integrity in the communication stack.

The second development was the OPC Classic that shaped an architecture using the client-server model for information exchange. The advantage of the approach in OPC Classic can employ the definition of different APIs for different specialized needs without a network protocol definition for inter-process communication [3]. Unfortunately, OPC Classic suffers how to enhance security in industrial networks when OPC Classic was used. Along with the OPC Classic, the first data access modeling has been developed for

## **2.1 BACKGROUND OF OPC UNIFIED ARCHITECTURE IN WEB ENVIRONMENT**

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reading, writing and monitoring the value changes. When a user requires inserting a simulative model with metadata, OPC Classic supported the simulative model in a limited way. Taking into consideration the limitations of OPC Classic, OPC UA came out into industrial communication.

OPC Unified Architecture (OPC UA) was developed by considering the drawbacks of the traditional OPC Classic Platform, which is a platform-vendor independent and service-oriented architecture. The primary motivation for migrating from OPC Classic is that its message protocol based on the Component Object Model, so OPC UA should have supported multiple communication protocols and operating systems [4].

The OPC Classic did not aim to connect end-user devices to the underlying protocol. To remedy this drawback, OPC Unified Architecture, integrates all the functionality of the individual OPC Classic into an extensible framework turned out to be a de facto standard and released in 2008 [5]. After obtaining a design regarding loosely coupled, coarse-grained, and service, OPC Unified became capable of integrating into web applications.

Few researchers have addressed the issue of the viability of OPC Unified Architecture on a web platform. [Cavalieri, Salafia & Scroppi 2018] [6] make an effort to enhance interoperability with web technologies to comply with web environment using Representational State Transfer mechanism. After publishing an article [6], they proposed research for end users who do not know the technical background about OPC UA Protocol and one can use a web application that provides a token-based authentication[7]. The research studies referenced as [6][7] offer a new concept for loose-coupling architecture at back-end development and advanced subscription system and asynchronous message broker protocol for MQTT, AMQP, and SignalR.

Furthermore, the authors listed and implemented the most crucial service elements such as SecureAccess, GetDataSources, ReadInfo, WriteInfo and Subscription through assuring grant access to the services. They have implemented an application for Publish/Subscribe architecture of OPC Unified architecture with REST calls. Besides, the authors have designed the whole system in a unified backend architecture without a front-end architecture. The drawback of these papers is that it does not implement a front-end application to scale in a web architecture in the context of user interaction and performance. In addition, the authors have mentioned the discovery service of OPC Unified Architecture, but they did not express how to integrate into web application architecture or how it could be beneficial for a web application.

## 2 STATE OF THE ART

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The authors justified the algorithm decision as middleware, user request module, and OPC Client Module. The studied algorithm reproducible but not easy to configure for testing [8]; nevertheless, it can give us insight and design decision. The implementation and research have conceptual differences about REST API definitions, Publish/Subscribe implementation, and serialization of data. However, [Cavaliaeri, Salafia & Scroppi 2017] emphasized that it is a novel approach based on a Publish/Subscribe pattern and stated all other solutions that relate to RESTful API integration into OPC UA requires handling the communication stack of OPC UA [7]. [Paronen 2015] stated that the author examined the requirements for the generic client and concerned with the selection of technologies as back-end development and front-end development. The author defined the core problems that are mixing the techniques in a monolithic application, stateless mapping API onto stateful OPC UA Sessions, incapable of supporting multiple service instance, and a performance bottleneck in the web client aspect of round-trip times between the client and the service [9]. Accordingly, the author emphasized that industrial plants generate vast amounts of data, which is a need for semantic understanding data and decision-making software [9]. The author implemented the features of reading over Historical Data, browsing in the Address Space, Subscriptions and calling Methods through the service layer and presentation layer.

[Grüner, Pfrommer & Palm 2015] introduced a concept relevant to RESTful integrability of OPC UA [10]. The main advantage of this paper has quantitative results to show performance through transport layer protocols such as TCP and UDP, and they have given a clear comparison among various types of machines such as Raspberry Pi. X86 PC and WAGO Device [10]. At the protocol level of OPC UA, they have introduced a good concept with a stateless and stateful process. Although this approach is interesting, it suffers from practicability of service sets with web platforms. [Grüner, Pfrommer & Palm 2016] published another paper that has significant results about the communication between REST and OPC UA by referring to reduced communication overhead, caching layers, stable service interfaces [11]. Unlike [10], they have mentioned the importance of load balancing the caching ability of REST on the Network Level [11]. In any case, these two types of research have not targeted to implement a web-application on the application later, but evaluations could be valuable in terms of session initialization in OPC UA and outcome over the roundtrip time of REST Protocol on OPC UA Sessions.

[Shiekofer, Scholz & Weyrich 2018] attempted to map OPC UA Protocol onto Representational State Transfer System by listing the features that they need. The authors empha-

sized the main problems such as HTTP Mapping, Sessionless Invoke and Browser Support[12]. It is generally accepted that their problem sets, but full-scale integration architectures, an architectural overview of the application, and details of implementation have not been addressed.

## **2.2 Background of the Question Answering**

Principally, a question answering system is a system to answer a question by human interaction concerning information retrieval and natural language processing theories. Open-Domain Question Answering identifies the question can be asked to a general type of data sources such as DBpedia, Freebase, Wikidata and so on. Not only a specific domain can be queried, but also a user may request in any question so as to get an answer from a data source. Closed-Domain Question Answering allows that a user may ask a question against a restricted type of data source that has defined in which a commercial domain resides. A user cannot ask all kind of questions so as to get an answer from a restricted data source. Closed-Domain is a broader term than restricted domain; hence, we will use restricted-domain question answering or more specifically semantic question answering in the rest of the research. A semantic question answering exploits linked data or semantic triples, which could represent ranging from linked open data cloud to a restricted domain. Linked open data cloud might be associated with any topic such as geography or social networking, and it has been made by multiple institutions, department and research facilities all over the world. Whereas, our domain type is restricted with a restricted factory domain so that we initially will focus on researches about the characteristics and features of a semantic question answering at this chapter. Then we ought to examine algorithms and application that has specified in domain-specific question answering.

Regarding the Semantic Question Answering, researches mostly focus on algorithms on how to transform from a natural language query to SPARQL Protocol and Resource Description Framework (RDF). A semantic question answering can use different types of dataset range from structured data to streaming data. Primary data sources are plain-text documents, open data cloud (Wikipedia, DBpedia), time series value, and linked triple data.

Few researchers have addressed the problem of restricted-domain question answering. [Molla, Gonzalez Et al. 2007] overview the main characteristic of a question answering

## 2 STATE OF THE ART

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in restricted domains is the integration of domain-specific information either developed for question answering or disclosed for other purposes[13]. The authors define the main characteristics of the question answering system over limited domains as below [13];

- It should be circumscribed
- It should be complex
- It should be practical

Circumscription motivates a user should know what kind of questions are available to the domain. [Molla, Gonzalez Et al. 2007] assumed that the more restricted domain is, the more likely obtaining data from comprehensive databases [13]. Developing a system in a complex domain, it might become difficult to manage all context of data. [Molla, Gonzalez Et al. 2007] emphasized that users should be aware of the level of detail expected from the answers and frequently searched questions in a practical manner [13].

The authors have compared between open-domain and restricted-domain question answering by figuring out key points. According to their paper, they have defined three clear-cut subjects, which are [13]:

- The size of data
- Domain Context
- Use of Domain-Specific Resources

[Molla, Vicedo 2007] figured out the main issue that they defined the restricted domain question answering may not use the ontologies of the open domain because it has too fine-grained structure [14]. The authors emphasized that developing a system in a specific domain could be time-consuming; therefore, one should consider porting a framework from other domains [14]. [Tirpude, Alvi 2015] presented a closed-domain question answering for law documents, which employs question processing module, document processing module, and answer processing module respectively [15]. As being a plain-text document-oriented question answering, the authors developed an algorithm in answering questions for plain-text documents by scoring the created answers. The practical implementation has been carried out clearly; hence the authors reached some results such as F1-Score = 0.62, precision = 0.92, and recall = 0.62 within 100 questions overall. Example of questions has been constructed mostly factoid questions that means constrained with “Wh-Questions”. [Chung Et al. 2004] has been proposed a restricted

domain question answering that works with weather forecast data. They have used a named entity tagger, and dependency parser was used to analyze the question precisely [16]. Although their practical system transforms natural language queries into the relational data query known as SQL, [Chung Et al. 2004] mapped the particular keywords onto the column name of the relational database. Answers were generated with a rule-based method which each query frame has an answer generation pattern for a frame [16]. [Chung Et al. 2004] has designed a paper that did not elaborate the algorithm, but we can take into consideration the precision and recall values which are 90.9 % and 75.0% respectively [16].

[Nguyen, Kosseim 2004] focused on the problem of precision performance in a restricted question answering [17]. The authors stated that the TREC or regarding open-domain question answering test datasets are less helpful for evaluating a restricted domain question answering. They criticized that lexical and semantic techniques such as WordNet similarity analyses may not apply well in the context of a restricted domain question answering [17]. The authors designed a term score system that trained with the predefined particular keywords to increase the precision of the question answering. The data source of this restricted domain question answering is a manually collected document set. The authors created a system called Okapi Formulation that has reached with 60 questions to 53.8% accuracy rate under a particular document set [17].

We have introduced characteristics and features so far. Currently, we will examine the algorithms regardless of being open-domain or restricted-domain.

[Dwivedi, Singh 2013] briefly survey the significant characteristics and algorithm types of QA Systems. They have defined the approaches as a linguistic approach, statistical approach, surface pattern based, and template based. The authors compared the linguistic, statistical, and pattern-based approaches by semantic understanding (Deep or Shallow Parsing), heterogeneous data handling, reliability, scalability, evaluation technique (manually developed, TREC, CLECT, NTIRC test set and so on) and application area (open domain, restricted-domain etc.) [18] in the discussion of the paper.

[Tatu Et al. 2016] proposed an article that described a semantic question-answering engine for merged structured and unstructured datasets [19]. Even though their proposal may process on generated semantic triples from a plain-text document on the biomedical domain, triples were created labeled such as “<lymterms: text> won </lymterms: text>”. Another advantage of the paper of [Tatu Et al. 2016] is calculating semantic closure between lexical chains by implementing a hybrid identifier with the part-of-speech, lemma,

parsing path to Wh-word, and named-entity recognition [19]. The authors followed a heuristic approach with answer ranking after making a query formulation, and they tested over 232, 585 n-triples with the mean reciprocal rank formula (MRR) [19].

[Celikyilmaz 2006] proposed a Bayesian Model method in different fields of natural language processing to help extract information from unstructured text. A probabilistic method that each topic-word in a document assigned to the 50 fine-grained named entity types were used [20]. The Latent Dirichlet Allocation has been used to search for a probabilistic match given topic and word in terms of word-topic position. One major drawback about the research is lack of evaluation of the algorithm.

[Unget Et al. 2012] defined a problem that most of the questions answering systems translate the question into a triple to match RDF data directly in open-domain question answering [21]. The authors proposed a solution to remedy the problem by creating a SPARQL template that provides a straight match into the internal structure of a question. They applied similarity metrics and search heuristics that consist of named-entity recognition, semantic representation by parsing, and POS Tagger [21]. The main advantage of the paper is that the system tried to detect properties of triples employing string similarity algorithms for entities such as Levenshtein and substring regex finder [21]. The main disadvantage of the algorithm is that the system does not care about the adjoining subtrees among entities except for the interchanged relationship between verb and nouns.

[Palaniappan, Sridevi & Subburaj 2018] focused on a question answering system by generating a template-question and semantic similarities of inputs in the e-learning domain. This work aims at a different type of questions with different patterns that have to be matched with the ontology tree structure in a document-oriented closed-domain [22]. Their architecture consists of tree tagger, WordNet similar matcher, ontology-query mapper, and a POS Tagger. There is a tree tagger parser to identify question patterns such as “give”, “define” or “what”, instead a question classification does. Synonyms of the noun/verb/adverb and adjective were checked with WordNet to map onto ontologies [22].

[Ferre 2012] has published one of the detailed research that expresses common pitfalls of natural language processing, essential points while consolidating SPARQL query language and morphological definitions [23]. SQUALL is a solution for querying and updating RDF graphs by exploiting a controlled natural language which restricts grammar structures of a sentence in order to diminish the complexities aspect of morphological structures the given input [23]. It has grouped all substantial features of a morphological

language and pointed out what type of elements in a natural language harnesses with regarding priorities and orders. The main contribution of [Ferre 2012] is categorizing ambiguities of natural languages and advantages of using a controlled natural language by sketching a translation from their intermediary language to linked data triples to gain more accuracy with their system [23]. [Luz, Finger 2018] aimed to transform natural language sentence into a query of SPARQL. They have used so-called dataset Geo880 that contains geographical questions and their answers respectively [18]. They proposed a neural network architecture that learns through an encoder-decoder model that generates an input-output sequence by reading each word of input to update states of the Recurrent Neural Network approach [18]. In their plan, they match the vocabularies with Glove word-vectors<sup>1</sup> for the target language lexicon at the first step. Then they implemented a sequence encoder-decoder model to map onto manually built SPARQL templates [18].

Restricted Domain Question Answering evaluation has been tailored from Open-Domain Question Answering. [Diekema, Yilmazel, Liddy 2004] has criticized the test questions developed for a restricted-domain question answering through open-domain question answering parameters [24]. The authors stated that task orientation becomes essential in evaluating a restricted domain question answering. Their data source is plain-text documents in the aerospace domain that includes academic content of aerospace engineering. Mainly, [Diekema, Yilmazel, Liddy 2004] split the parameters up as performance testing, data source testing, and user interaction testing. The performance testing includes speediness and availability of an answer in responding to a question. While the data source testing was observing the scope, coverage, size, and updatedness of their data source, the user interaction testing specified the testing phase as querying style (Keywords, sentence-based), question formulation assistance such as spell checker, abbreviation recognition and feedback collection [24].

//Give a table about algorithms and approach

### 2.3 Linked Data Collection for Heterogeneous Data Source

Linked Data Collection is not part of our research objective, but we will overview approaches for the sake of the semantic question answering. We should conduct a literature

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<sup>1</sup> <https://nlp.stanford.edu/projects/glove/>

review to find out the status of the researches. Linked Data Collection for the assistance software can be examined within two sections.

### 2.3.1 OPC Unified Architecture Information Model Serialization

Firstly, linked data serialization from OPC UA Servers to convert Information Model into a linked data format. There is a research gap between OPC UA Communication Stack and linked data model, and it appears that researchers' circle have not conducted enough surveys, researches, and statements. Information model provides standardization of information representation to be understandable by the several systems. We will research the serialization of the OPC UA Server Information Model into the linked data.

[Katti, Plociennik 2018] proposed an approach about the integration of OWL linked data language into application-specific methods of OPC Unified Architecture. The emphasized that the absence of a standardized information model for machines, each vendor may implement their data and information model to devices [25]. Their aim to create a semantically augmented OPC UA framework that enhances the knowledge in production for decision-making systems [25]. The authors of the paper defined the essential parts of OPC Unified and OWL linked data structure that should match each other. For instance, they mapped "serviceName" of OWL document onto "OPCUAMethodName" of OPC Unified Architecture. The ontology service creates the ontology statically through the various process of the factory such as welding machine, color-spraying machine. They have not published test and application details except for a piece of images related to sample created OWL data. [Pfrommer, Grüner & Goldschmidt Et al. 2016] offered a technology-independent common core for information modeling to overcome various information model from different machine-to-machine protocol [26]. The difference of their approach is creating a uniform information model that can adapt the information into SQL Database, memory-mapped values, OWL ontology or AutomationML formats[26]. The difficulty of their approach that a platform should discriminate the containment relations, inheritance relations and type-instance relations of the Information Model in order to assign to particular ontology items [26]. They have cleared the intermediary language before mapping onto a semantic ontology; hence there would be a performance advantage.

### 2.3.2 Linked Data Collection from Streaming Data

Secondly, we will search over the linked stream data processing to create format suitable to linked data. Linked Stream Data Processing with linked data is the primary research topic in Industry 4.0 and Smart Factories. Previous studies mostly defined Semantic Representation as a challenge that is supposed to map from the time-series data onto linked data. Raw sensor data is useless unless without being adequately annotated.

Previous studies mostly defined the linked data collection from streaming data as a challenge because mapping from the time-series or real-time data onto linked-data creates different nature among them. [Su Et al. 2014] offers a mark-up language for representing device parameters and measurements [27]. The authors organized research for a sensor markup language that used to describe sensor measurements and device to find the gap between semantic representations and data formats [27]. SenML is an intermediary language for sensor measurements, and they convert this language to linked data. [Wang, Zhang & Li 2015] have defined two main rules to implement a semantic annotation, which is transformability to multiple RDF sources such as N3, Turtle and automatic assignment of a namespace to be specified on the sensor and actuator applications [28]. The biggest drawback of this paper that was poorly designed to show how an intermediary language could be converted to another language.

Establishing a way to extract automatically from unstructured time series data into linked data is a challenging problem. [Llanes Et. al., 2016] states that the real-time approaches of linked data suffer from the main limitations which are [29] :

- 1) Triple storage cannot efficiently handle high update rates
- 2) Numeric reading has performance issues with complex SPARQL queries.
- 3) Extracting sensor data triples are different

As being a survey paper, [Llanes Et al., 2016] categorized real-time data for linked data with a selection of ontologies, defining the mapping language, choice of continuous queries, choosing related datasets in Linked Data Cloud Storage and creating data linkages [29]. Each chapter have given a definition and current research in the market, and it can be summarized as below:

**Selection of Ontologies:** Ontology selection is a crucial step to perform streaming linked data from time-series value. Every platform has its specifics, and it should be handled

with proper RDF datasets such as OWL, Turtle, and N3. Lack of scalability from a semantic data source to another, platforms should use standard semantic dataset and annotations. [Llanes Et al. 2016] offers to use Semantic Sensor Networks that can describe capabilities, measurements, and resultant from sensors and actuators [29].

**Defining the mapping language:** To convert sensor-based data from time series into Resource Description Framework, a converter needs an extra layer to customize mappings from relational or non-relational databases to RDF datasets [29]. [Llanes Et al. 2016] demonstrates two approaches which are: R2RML [Calbimont, Corcho & Aberer 2011][30] and SASML [Zhang Et al. 2015] [29]. Those languages are in common that the platform works with time series streaming value should have a mapping layer in order to send a SPARQL request. While R2RML were implementing a sensor network that contains predefined annotator to match every possible sensor or devices with a framework in particular ontology language, SASML used to annotate sensors and devices in extensible markup language simply.

**Selection of continuous queries language:** The authors stated that expressions such as SPARQL are designed to execute RDF triples in a static way, however SPARQL query has no effect on streaming linked RDF triples so that new RDF Stream Processors were implemented by [Barbieri Et al. 2009], [Calbimonte Et al. 2011], and [Anicic, Fodor 2011]. They named the new language C-SPARQL and Event Processing SPARQL respectively [29].

[Anicic, Fodor 2011] proposed Event Processing SPARQL (EP-SPARQL) as a new language for complex stream events [31]. The primary goal of their proposal is to provide a fundamental framework for Event Processing and Stream Processing [31]. The authors created a new quasi SPARQL language that has some similar functionality such as Seq, Equals, OptionalSeq, and equal optional used to combine graph patterns in the same way as Union and Optional in SPARQL [31]. While event processing is adjusting the time window size in SPARQL, stream reasoning organizes the subject-predicate-object triples coherently. EP-SPARQL language can take advantage of query optimization and pre-processing over the static and dynamic part in data space unlike C-SPARQL [31]. C-SPARQL is an older version of EP-SPARQL that consists of RDF streams, Windows, Registration, and Aggregation [32]. C-SPARQL language is less complicated than EP-SPARQL. RDF Streams are locators of data source identified by Uniform Locators. Windows describes many given triples should be in the timeframe. Aggregation and Registration provide similar functions such as bool indicator, average, sum, min and max in the same way in SPARQL.

[Hasemann Et al. 2018] proposed an RDF tuple store named Wiselib that attaches into sensors to collect data employing RESTful architecture that can connect to Linked Data [33]. The Wiselib on the lowest level, it uses a set of protocol that a sensor can understand at the same level. On the highest level, it uses HTTP protocol to understand semantic web documents as a proxy server. As an extra feature, the tuple store can behave as a SPARQL endpoint by basic query parameters such as browse and insertion statements [33]

## **2.4 Chapter Discussion**

Previous researches about OPC UA integration to RESTful API profoundly gives advantages and disadvantages with the implementation details. As of yet, there is no examination to show an architectural design that can be compatible with industrial manufacturing. Except for a solution created with research[7][8], other research algorithm or data set are not reproducible. No research has been conducted overlaps with our research goals in the thesis. We will elaborate given algorithms on previous studies regarding OPC UA-Web Integration, the heterogeneous data source, and the semantic question answering.

First of all, OPC-Web Integration has not been overviewed about architectural design of backend and frontend application in any manufacturing domain. Besides, there are some meaningful design advice, outlines, and evaluation in the research [9][7][6] [34]. The research in [Cavalieri, Salafia & Scroppi][6] [7] has detailed the Publish/Subscribe implementation of OPC UA. They created a monolithic architecture without balancing, discovery service, and front-end architecture. [Paronen 2015][9] has defined the scope as a practical implementation of supervisory control and data acquisition system, historical data acquisition and monolithic service and presentation layer architecture. Not all the other researches are similar to our research goals; nevertheless, they can help the thesis with their knowledge base of communication stack and possible implications they have found. [Grüner, Pfrommer & Palm 2015], [Grüner, Pfrommer & Palm 2016], and [Shiekofer, Scholz & Weyrich 2018] addressed the problem set at the protocol level, which is regarding network communication.

Serialization of OPC UA Information Model grouped into semantic sensor network-based approach and adapting information model approach. The semantic sensor network is still hard to implement and understand without a knowledge base of the

underlying system. It has been a bottom-up approach ranging from sensors to main manufacturing devices. Unlike semantic sensor networks, generating a uniform information model could be a top-down approach, but the system would be generic to every industrial communication system. The thesis handles OPC Unified Architecture so that there will be no need to apply these approaches.

As for the semantic question answering, each approach can solve the specific domain problems. It is a cumbersome task to analyze every application in open-domain, closed-domain or restricted-domain question answering; instead one can examine the fundamental algorithms. Rule-based and statistical learning based methods come to the forefront depends on the issue that all authors faced. [Molla, Vicedo 2007] offers a framework from other applications to one who wants to develop a restricted-domain question answering. [Molla, Vicedo 2007] listed the essential features of restricted-domain one can consider them while developing a system. [Tirpude, Alvi 2015] and [Nguyen, Kosseim 2004] propose a modular approach such as question processing module, answer ranking module in the making from questions towards answers. [Dwivedi, Singh 2013] has been specified the algorithms as categorical, which is a quite important guide for existed algorithms. [Tatu Et al. 2016], [Celikyilmaz 2006], [Palaniappan, Sridevi & Subburaj 2018], and [Unget Et al. 2012] have employed statistical methods to reserve morphological structure of a language. Advantages and disadvantages of their approach might not be easily observed because every approach is special to its domain and test set. Significantly, [Ferre 2012] has offered a controlled natural query that can restrict the grammar structure. The controlled language can eliminate the methods of pattern-based, template-based solutions and it can benefit less resource from statistical language identification.

Consequently, insufficient test data and lack of producible algorithms are perplexing the reliability of algorithms in the domain of smart factory. Another fact is that the algorithm strongly depends on the test and training data; therefore considering requirements of the field can give us a more significant contribution, rather than implementing in the thesis credulously. As for the OPC Unified Architecture with REST integration still has a problem to combine at a different level of network communication. Architectural design and application field of an OPC UA web-platform in previous studies have not given much detail that we can follow.

### 3 Industrial Communication in Smart Factories

The fourth revolution of Industry as known “Industry 4.0” fostered the exchanging data communication between interconnected devices in an industrial plant. The primary objective of Industry 4.0 was making the manufacturing technologies of factories more intelligent, optimizing the chain of processes and enhancing capabilities of communication one to another. Industry 4.0 enforced end-to-end digital integration of engineering throughout the value chain to facilitate highly customized products, thus reducing internal operating costs [35]. Regardless of being the context of manufacturing, Industry 4.0 has changed communication infrastructure between devices and machinery industrial communication working groups have always aimed in industrial plant requirements Increasing efficiency and productivity that has required. Having a unified digital platform for industrial communication, devices and machinery can communicate with each other regardless of vendor-specific applications. Interactive assistant tools, transformation ability, and efficiency in production are key factors that can affect the future of digitalized factory.

A smart factory is a highly digitized and connected production facility that relies on smart manufacturing [36] — this concept one of the key outcome of Industry 4.0, which intelligently changes manufacturing technologies. The central power of the smart factory is making data collection possible. Additionally, sensors enable the monitoring of specific processes throughout the factory that increases awareness of what is happening on distinct levels [37].

The definition of smart factories has evolved over the past few years. In the present studies, a smart factory has defined an aspect of boosted technology of Industry 4.0. Impact of manufacturing development affected economic growth over the last decade in Germany. Continuously improvement of Industry 4.0 brought the researchers to find cutting-edge technologies such as Question Answering System; Manufacturing Augmented Reality, ChatBot System and so on. The critical aspect of Smart Factories can be list as follows: Towards Smart Factories, Industry 4.0 and Human Machine Interface in Smart Factories. Within the essential aspects, this study informs the readers how it contributed to the Industry 4.0 area and what will be the benefits when used by Smart Factories.

Consequently, it is necessary to integrate the value chain by using cyber-physical systems digitally has been demanded [35]. The Cyber-Physical System embraces complex networking, integration of embedded systems and application systems, enabled by

Human Machine Interaction [38]. Smart operators should be enabled to realize the helper system to humans in increasing interactivity and ergonomy.

A cyber-physical system describes the relationship between humans and a Cyber-Physical System, which is divided into a physical component by separating virtually from each other[39]. Taken as a whole, physical components and their virtual representations should standardize from the bottom to the top.

#### **3.1 Human Machine Interaction and Smart Operators in Smart Factories**

Manufacturing is one of the critical areas that should communicate with humans clearly to increase the overall efficiency of a factory. After Industry 4.0 has been initiated, the new industrial development revolutionized by the integration of interconnected devices into manufacturing systems. Although the digitization of manufacturing process has changed the sense of human operating, the human operator still is a core element of industrial automation. The decision makers planned the industrial automation to eliminate the cost originated by human operators. Even though many devices in a plant can handle the processes automatically and robustly, those processes should be optimized and maintained by human operators. The Human Machine Interaction is a term utilizing for the relationship between humans and machinery, which can be managed by a smartphone, terminal device or monitoring device. Moreover, human-machine interaction such a complex system organizes among human operators, process control systems, and people at management in a smart factory.

Actionable feedback through smart devices became significant so that the human operator reaches information anywhere and anytime in a smart factory. Those smart devices can use desktop applications, tablet applications, embedded controller applications or web applications. Continuous monitoring over streaming data, browsing data through vendor-independent devices and natural language inquiring over heterogeneous data are essential skills that a human-machine interaction should provide.

With the improvement in the OPC Legacy Standard, the Industrial World achieved the interoperability between heterogeneous devices at the communications level, regardless of the manufacturer [40]. Question Answering systems increase the capability of transforming query languages. Semantic structured or relational data used to show result employing a particular query language SQL, SPARQL and so on.

The web-based solution has an advantage over developing a smartphone application or tablet application in accordance with scalability. Since a mobile device can reach to a server, the HMI system can connect all device according to the web server's configuration. Hence, the system may enhance user experience with Human Machine Interaction legacy devices in order to interact with the data of industrial processes [40].

A human operator should obtain various kind of stimulus with an assistant application to initiate a situational recognition that conveys to problem-solving step. Such tasks predictive maintenance or diagnosis on sensors or actuators is not possible without knowing the underlying structure. Nevertheless, a smart operator can help to solve this type of issues that human operators faced, beyond that the human operator can inform about situational analysis to the management personnel. Throughout all process may affect the decision-making process or at least informative resource would be obtained in a short amount of time.

In our case, experts may employ the average value of a specific sensor that resides in a machine to predict future maintenance or repair. The system can also provide an error situation with a threshold value when querying into time series data. Because of domain-dependent data, a question answering system complies with the factory specific data. The data may contain many specialized terms that experts use a keyword or plain text to search for an item related to a machine.

## 3.2 OPC Unified Architecture for Web Applications

### 3.2.1 OPC UA Service Sets

OPC UA has low-level communication stack and high-level applications on the communication stack. Because non-existence of a set of subroutine definitions for communication stack, services are conforming to their service sets. To implement a web-based application, OPC UA Services must be suitable with regarding web architecture. OPC UA Services have fundamental specifications and requirements for each service. Each service has service sets that show abstract descriptions, and they do not implement specifications [43]. These services could be discovery service set, secure channel service set, session service set, query service set and subscription service sets. Discovery Service set used to find an OPC UA Server endpoint that has connection string by conforming au-

tomatically or manually. Secure Channel service set ensures the confidentiality and integrity by certification exchange among clients and servers [43]. Session service set used to create a session with the secure channel service set to reach an address space of a server. Query Service handles current and historical data concept to return bulk data from an address space. Lastly, the subscription service sets have a set of polling item called *MonitoredItems* defined by clients to notify progressive changes in a particular time interval [43]. So far, we have explained the abstraction layers of OPC UA communication stack for higher-level functions. The following parts will introduce the necessary parts that we examine in the thesis.

#### 3.2.2 OPC UA Address Space Model

The primary objective of the address space in OPC UA provides a standard way to the clients in terms of elements of OPC UA. More specifically, the Address Space provides an area to objects that can realize to exchange information. To exchange information, the address space act as permanent storage transforming from binary data to high-level objects. In the very beginning, OPC UA has specified as an object-oriented model, and every element of OPC UA need to correspond for objects. OPC UA had to comply with this standard. Clients can browse, read and write using nodes in the address space.

The smallest item in the address space of OPC UA names Nodes which belongs to Objects [44]. A node comprises Attributes and References which can be reached by Node Class Browse Name [44]. Attributes define Nodes, and a node can connect to other nodes with the interconnected information of References. OPC UA Nodes have several classes such as Object, Variable, Method, View, Object Type, Variable Type, Reference Type and Data Type [45]. When a user is endeavored to obtain values of the node, the address of the node in Address Space of OPC UA should be activated. Mainly, a browse name and node-id show to clients in the address space. To access attributes or other elements, clients must know the name of browsing and a related node ID. Due to a real-time data processor, the address space has a breakthrough feature where process data saved previously. This thesis is a review of a preliminary attempt to explain items of address space which are [46]:

**View:** All Nodes lives in a View when browsing in Address Space.

**Object:** It represents real-world objects and software components, and it may use References additionally to define relationships of Nodes.

**Variable:** The purpose of a Variable is to provide a real-time value when a client is browsing in it.

**Method:** Method item correspond to callable events by returning a state

The things as mentioned above defined as the general aim of OPC UA Address Space. There must be data containment when we use these items. Mandatory and Optional selection are contained in type definition so that one can decide how to apply a type.

**Object Type:** It consists of a definition for Objects

**Reference Type:** This type used for meta-modeling providing an inheritance of objects and defines meanings of a relationship among nodes.

**Variable Type:** It defines some types such as Historicization of Variables, Minimum Sampling Interval, Access Level, User Access Level, Array Dimensions, Value, and Object Type. Variable Type has a vital role in practical implementation because the definitions of Variable Type enables browsing, reading, writing, and subscription how to make them possible.

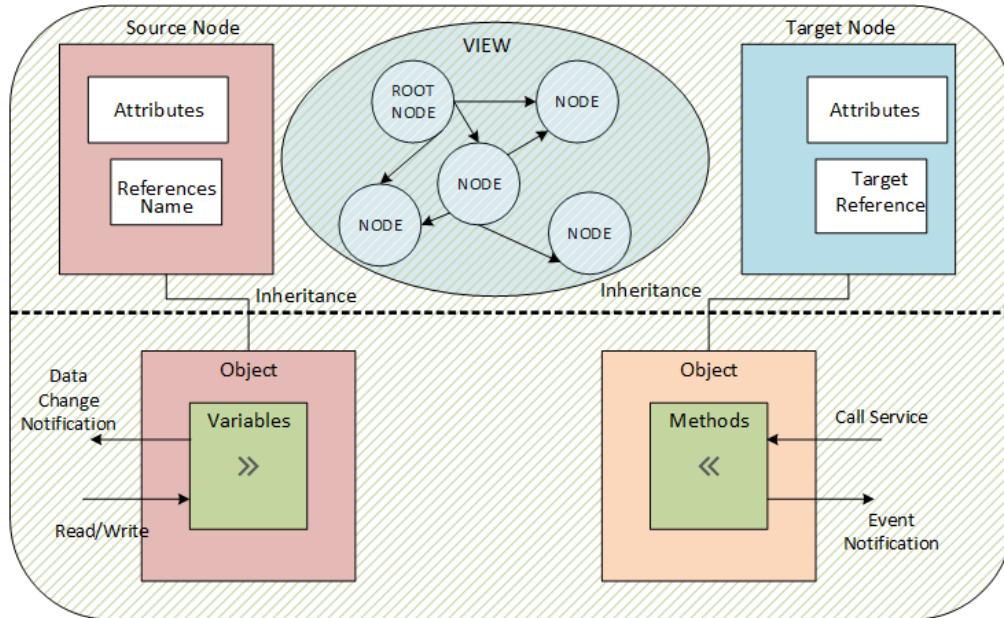


Figure 3.1: OPC UA Address Space [44] [43]

As shown above, an address space consists of nodes. Each node has fundamental attributes and references. Object classes have variables and methods to embody object-

oriented architecture. Nodes connect to each other in an address space through a service called View. Upper space that has separated by a dashed arrow shows an address space and below one demonstrates an information model that inherits from and links into address space. The View Service in OPC UA helps to navigate hierarchical references to search for information about nodes, attributes, and objects of nodes.

#### 3.2.3 OPC UA Information Model

The primary objective of the Information Model is to represent the structure of the objects that have relationships with Variables, Methods, and Events and provides a set of predefined types and rules which can be expandable [46]. Beyond this concept, a semantic modeling tool provides a two-way standardized communication version of an Address Space. Strictly speaking, it is a way of object-oriented representation of servers that can be reached by clients. The main difference between Address Space and Information Model is suitable with meta-modeling languages such as UML and SysML. Information Model has a higher abstraction layer to simulate the Object-Oriented Paradigm of OPC UA Protocol.

As indicated previously, OPC UA is a protocol based on Service Oriented Architecture so that every object can communicate related service to exchange corresponding data. Object Types defines types of object dependent on the object, and these types can be customized with multiple definitions. Variables are the main components of objects that represent data values in the objects. Variable Type and regarding Data Type define a structure of variable. The challenge of any OPC UA Software shows all data types that relate to Scalar (Fundamental Data Type), or Application-Defined Data Type. Our method is a definite improvement when a user requires reaching a scalar typed or application-defined typed objects.

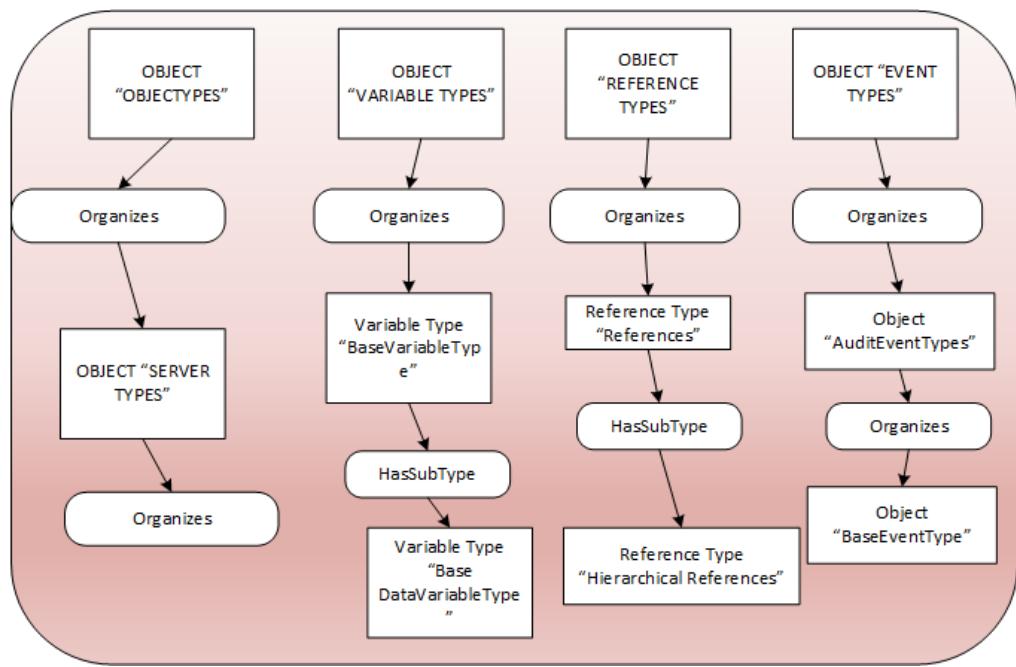


Figure 3.2: OPC UA Information Model [47]

Information Model defines objects, variables, events, and references relationship between them or inner structures. As illustrated in Figure 3-2, a reference organizes the relationship between object, more specifically Node Classes. Node classes are a subset of the abstraction method among nodes in the address space. Due to space limitation, Figure 3-2 indicates limited elements of the Information Model. For instance, reference has not only HasSubType, but also comprises of HasTypeDefinition, Organizes, HasProperty, and HasComponent. HasSubType defines subtypes and supertypes of references. While subtypes are specified explicitly, supertypes are identifying through HasSubType implicitly. For instance, the BaseType has multiple references as HasSubType, and with a BrowseName and NodeClass, it is defined explicitly as primitive, structured or XML elements. It is not a mandatory type of definition in references; nevertheless, it is a compulsory schema structure build up a hierarchy in OPC UA. HasTypeDefinition is a definitive term for the type definition of an Object. Every object has a relationship with other objects so that HasTypeDefinition should occur more or less the number of connections that an information model has. Organizes determine types of folders and their internal structures so as to group a set of objects.

Nevertheless, Organizes reference may be used for Objects of the FolderType, which has a usage restriction [44]. OPC UA Servers have useful items called Folders that serve as

separator objects that have similar type definitions. HasProperty used to describe Properties, which properties have relationships with other features of a Referent Type. HasComponent identifies the data variables, the Methods, and Objects contained in the Object [44].

Consequently, every element of the Information Model defines and has a relationship in a hierarchical way or a non-hierarchical way. In a general manner, the information model defines types and references, which are the essential component of abstraction. As a result, the web-based application depends on the information model for browsing between nodes with their reference and for identifying the types of the nodes, more specific objects, by using this service.

#### 3.2.4 OPC UA Discovery Service

The principle of SOA states a service-oriented architecture should have a service consumer, a service provider and a discovery service. The discovery service is vital to construct a microservice structure instead of statically typed endpoints. The practical implementation is able to use discovery service and then clear-cut key points described in service discovery of OPC UA. [Overviewing better the discovery process](#), these scenarios should be examined as follows. A client and a server can be in the same host or the same network. Moreover, a client can connect different servers which are in a different network.

In the discovery process of any network, a discovery service allows locating items of a network by a specified device of a network. For instance, a client can find a server via a proxy server without knowing any details except the address of a proxy server. OPC UA Discovery Services work with the same principle by using endpoints to establish communication between OPC UA Clients and Servers. Discovery Service at OPC UA Standard can be divided into two main topics in terms of application domain where application lodged in. These are “LocalDiscoveryServer” (LDS) maintains discovery requests for all applications if clients and servers are on the same domains and “Global Discovery Server” (GDS) preserves discovery information for all applications if clients and servers are on the remote domains [43]. GDS can be full-fledged OPC UA Server and centrally organize other discovery services. Conversely, LDS can only behave as a service or serve other LDS supporting multicast networking. In this work, a local discovery server is examined in terms of benefits and drawbacks on the existing architecture. A client that requires connecting to a real server through a discovery server should use

a set of service sets which are “Register Server”, “Find Servers”, “Get Endpoints” and “Find Servers On Network” [43]. When a client requires establishing a connection, a session is not supposed to be created. Hence, every server has a Discovery Endpoint to connect clients without creating a Session [43]. However, this could be a security vulnerability because a client and a server do not share certificate among them and lack of a session creates an unsecured connection.

A Discovery Server has two types of endpoints, which are discovery endpoint and registration endpoint. While a discovery endpoint provides a connection to clients, registration endpoint awaits a result from discovery endpoint whether it has a connection with the client or not. After a client obtains a “GetEndPoints” service set from a discovery process, it can open a secure channel by providing a certificate, hashed authentication or anonymous way to perform opening a communication channel. Accordingly, the between finding an endpoint and sending the endpoint request has not authentication schema. Hence a discovery service implementation could cause a security vulnerability inter smart factories.

| <b>Architectural Decision</b>                             | <b>Advantages</b>                          | <b>Disadvantages</b>  |
|---|--|---|
| <b>Industrial Communication with Discovery Service</b>    | Suitable with Micro-service and SOA Design | Insecure connection before getEndpoints between Client and Discovery Server |
| <b>Industrial Communication without Discovery Service</b> | Suitable with Monolithic Design            | Lack of automatical endpoint discover                                       |

Table 3.1: Discovery Service Pros and Cons

#### 3.2.5 OPC UA Subscription Service

When a stateless architecture such as RESTful API implemented onto a stateful architecture such as session-based protocol, there would be an issue for identifying alteration of data. As streamed data incoming from servers, the stateless architecture such as RESTful

API has a deficit to refresh data instantly. A simulated data that is continuously changed has a considerable overhead when sending a read request over again. Moreover, data fluctuation has a vital role in analyzing data by experts. Hence, instead of sending a request, a subscription might have sent to identify a variable, attribute or object changes with a set of features. In order to remedy this repercussion, a subscription is sent with particular monitored items into a session and monitored items serve as a polling mechanism. As illustrated in Figure 3-4, a single monitored item and multiple monitored items attach to a subscription. This service reduces time and space complexity of reading request by showing all changes in a single subscription. Three types of changes can be observed in OPC UA Protocol to simulate data, which are data changes of Variables, Objects of Events or Attributes. The sampling interval is a critical component of monitorable nodes to detect changes in a particular polling time. After assigning a sampling interval, OPC UA Server can notify OPC UA Client when an Attribute, an Object or a Variable has changed. The implementation of web-based application dispatch a binary indicator belongs to monitorable nodes; thus the web service sends a general subscription request without monitoring nodes' topics and ID. A filter decides whether the next notification of a subscription should send or not. A filter can eliminate a different type of item to be monitored so that unnecessary notification cannot overflow in the system. A subscription service put all notifications into a queue that can transfer without blocking respective notification.

If a new notification has been entered to the queue, a prior notification should be deleted to free the queue size. Monitored items should comply with the minimum sampling interval. As a result, the minimum sampling interval defines the degree of the sampling interval, and this minimum value of the sampling differ from a node to another node. However, the underlying structure of the update cycle is not synchronized, so the system should explicitly synchronize all sampling values in order to fetch correct notifications with a decent value. Accordingly, the amount of the smallest minimum sampling interval can create a maximum load of traffics for OPC UA Server and lead to produce buffer overflow, **which is a general malicious attack that used by harmful minds.**

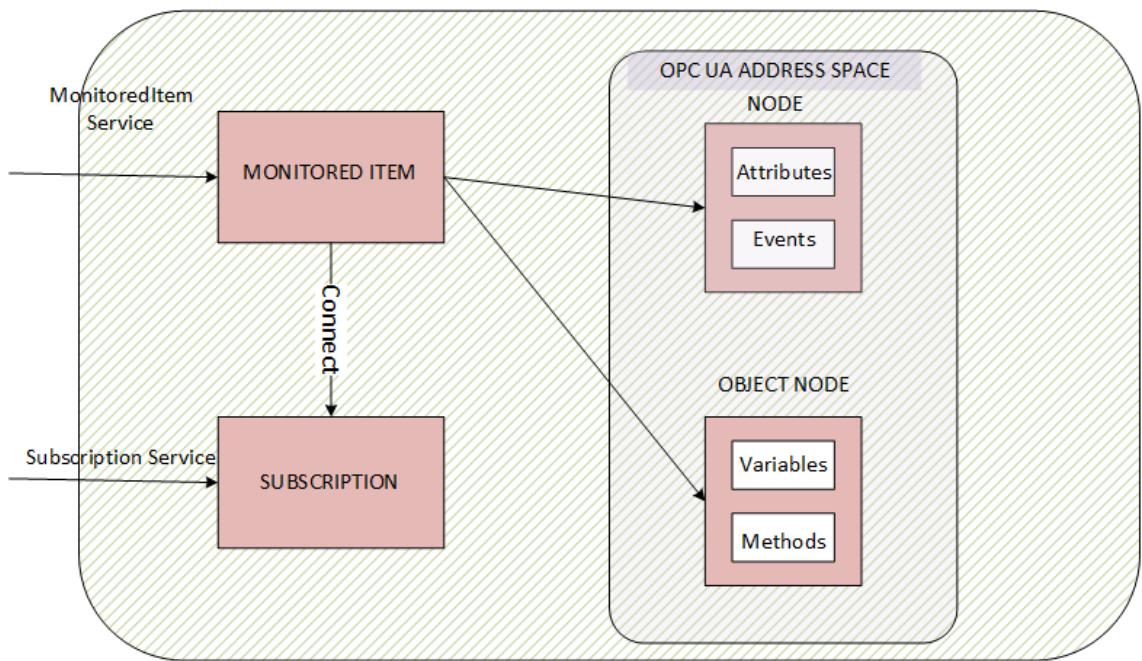


Figure 3.3: Subscription and Monitoring Item Services [43]

### 3.3 Chapter Discussion

Components of OPC Unified architecture have referred to data exchange structure, their definition in communication stack and abstraction methods. OPC UA Servers and Client are the fundamental elements of this research. Due to insufficient information modelling of communication stack of OPC Unified Architecture, each OPC UA Servers realizes its information modelling and address space. Moreover, data that has stored in OPC UA Servers have various definition and it can change the semantical understanding.

External connections of primary functionality of OPC Unified Architecture are organized with OPC UA Service Sets.

RQ1, RQ2, RQ4 should be answered.

Services of that design the concept of SOA architecture can alleviate design issues in a capable manner. However, the main issue is that a stateless web-based application enables communicating stateful OPC UA Servers. Discriminating the services of OPC UA may make the development phase easier for REST request. Session timeout could be a problem while reading or writing dataset to an OPC UA Server. If the operation timeout

of a single request is above than a session timeout, the number of failing requests are tend to increase, which is an undesirable result for the web-based application. Address Space Model and Information Model are essential services of OPC UA so that one can create a semantic model from an internal model of OPC UA Server. Publish/Subscribe and Subscription Service process the streamed data that changes quickly within a minor period in the production system. If a server closes a session silently, the OPC UA server does not delete regarding subscription, however, the server cannot observe data changes anymore. After setup a reconnection, a subscription may continue where the session leave off. As far as subscription feature concerned, a stateful architecture offers more advantage than the stateless one. Service orientation enables integrating RESTful architecture so that the web-based architecture can enforce a microservice architecture instead of monolithic architecture.

Smart Factories enables more analysis of produced data, integrable communication protocol, and advanced controllable manufacturing devices. Our proposal of the web-based software can speed up the controlling of multiple stages in a manufacturing process with OPC UA Services. OPC UA Protocol provides a clear abstraction and service-orientation to map a HTTP request onto the services.

//Discovery. Upon sessions it can be discussed what are those advantages.

//Subscription Service should be synchronized

//Session timeout and id problem of OPC UA

//Session and Monitorable Node Concept

//Importance of services

//Use your own words

//Significantly condense the original text

//Provide accurate representations of the main points of the text they summarize

//Avoid personal opinions

Services separate business function to provide a coarse-grained task implementation. Service performs as a coarse-grained task handler that provides breaking large tasks, low communication and synchronization, and assignment tasks into a large processor

core. However, service-oriented architectures suffer from load misbalancing, which loads of data is not assigned equally on business logic.

A Service Oriented Architecture should communicate business functions in the manner of having an asynchronous request/response. An endpoint is a universal resource identifier where the service can be found [42]. The primary motivation for migrating from OPC Classic is that its message protocol based on Microsoft's COM/DCOM (Mention about DCOM before), OPC UA supports multiple communication protocols and operating systems [4]. OPC UA Security is more enhanced and easier to configure. Updated security protocols and hash methods empower the data transmission between OPC UA Client and Servers. OPC UA application authenticity is provided by X509 certificates that assign to each application uniquely [4].

OPC Unified Architecture is breaking into several services that should be investigated. Our scope is to study services that would be an important step for the thesis. For instance, this study does not examine the Historical Data Access Service and Alarm Service because the web-based software only utilizes current values through OPC UA Data Access Interface. Our goal is to evaluate Data Access Interface and implement with an OPC UA SDK. In the following pages, this thesis will present the most important services used by the web service. We will evaluate the necessary components that can be used in this research to reach our goals.

## 4 Theory of the Semantic Question Answering over Linked Data

//Types of Question Answering

//Domain of Question Answering

//Types of questions which can be used in question answering

The question answering is a combination of natural language understanding and information retrieval theories. A question answering enables simple query rewrites without explicitly the use of a query language. On the one side, a question answering performs a task on natural queries to observe syntactically and semantically, on the other side it is an activity to obtain relevant information model that has been searched. Therefore, the major aim of a semantic question answering is to identify an answer from a collection of ontology data such as RDF, RDF/XML, Turtle, JSON-LD or N3. Question Answering is a theory in the middle of Information Retrieval and Information Extraction. Since those Information Retrieval and Information Extraction have perplexed definitions that one should examine with similar and dissimilar points, in order to better understand the question answering process. Information Retrieval is a term used for locating a document that is required by a user, but a user defines a relevant answer after obtaining a document. Information Extraction is a term for extracting a set of information from a user input so as to learn relationships between searched keywords and documents<sup>2</sup>. Broadly speaking, question answering is a balancing process with natural language understanding between natural language understanding and information retrieval.

According to the domain type of question answering as shown below:

//Ontology based Question Answering

//Context Based Question Answering

Ontology based Question Answering is a type of question answering

**Open Domain Question Answering:** A user can ask any topic that he wants to reach a result from a general domain.

---

<sup>2</sup> <https://www.ontotext.com/knowledgehub/fundamentals/information-extraction/>

**Closed-Domain Question Answering:** A user can only ask questions against domain-dependent document-based architectures. For instance, one can ask general questions against a specific text document which have collaborated by online sources.

**Restricted-Domain Question Answering:** It is more likely one can ask a question against semantic documents in order to obtain results. Main characteristics of restricted-domain are that data sources can be different from closed-domain and open-domain. In this domain, the answer and result sets are circumscribed and complex, so information retrieval capability is strictly relevant to natural language processing capabilities.

Question Answering System is broken into question types that will be explained within this chapter.

Question types handling is an essential step for any question answering. On the one side, closed-domain and restricted domain question answering systems used for eliminating the unrelated type of questions, on the other side open-domain question answering system takes types of questions to formulate with rule-based architecture. According to types of questions will be shown as below:

**Factoid Questions** are about providing concise facts. For instance, “What is the population of Berlin?” is a factoid question that should be narrowed down from a general topic into a specific one. Otherwise, an open domain question answering system would be ineffective against a factoid question.

**Non-factoid Questions** are the type of questions that have not concise facts. For instance, “did you perform well the task?” is non-factoid question because there is reasoning and induction to find out correct answer. These questions can be grouped as reasoning questions. A user may ask a question defining by reasoning keywords, e.g. “Can you tell me the system health in trouble?” or “Can our system stay alive?”. “Why” and “How” questions also show reasoning to induce a result from a series of events. The main reason that this research did not implement is that the types of questions have complex structure for statistical model and require a vast amount of data and answer ranking module.

**Keyword Search** is one of the basic search items that are used in search engines. In the early phase of the Internet, researches have been focused on how to extract documents from keywords. The simplicity of grammatical and semantical structures, a keyword-based search has always been a prominent topic for question answering. This work can use a keyword to extract information from the Turtle RDF data format with a specialized keyword. Verbs or more specifically predicates and objects counterpart nouns in RDF

are based on Fraunhofer IWU's data source. So one needs to have limited information about the internal system.

**Indicative Questions** is that an expert can make a sentence through request words in the sentences, e.g. "I would like to know what does linkedfactory contain?".

**Indirect Requests:** A user can ask a question like "I would like to list all of the members in linkedfactory?" or "Give me the value of sensor1 in machine1". The main feature is listing of the information

**Boolean Questions:** Answer must be yes or no. We have used this type of question to understand system status. "Is the system health good for sensor1 in machine1?" and "Is the //

The semantic question answering will be considered ontology-based question answering that can answer factoid questions in a restricted smart factory domain.

When this research has been conducted, one of the research problems was serialization and representation of non-linked data in a linked way. OPC UA Protocol allows presenting the data from various devices and human operators can interpret the data in a specific domain. Essentially, the meaning of the data cannot be interpreted by machines. This chapter summarizes a theoretical background how a machine infers from structured and unstructured data. Hence, this research comprises time-series and static data values of eniLINK and evaluation of the linked data sources to conceptualize a particular problem in the sense of machines. Time series or real-time values from sensors, software logs or business packages are supposed to be converted into a resource description framework in order to use their linkages. Time-Series Data Source from devices of the Internet of Thing makes a disadvantage situation as for real-time environment. The major drawback is to extract meaning from a network of deployed sensors. Because raw sensor data is useless unless properly annotated. While transforming raw sensor data, another drawback comes up limited resources in terms of processing, storage capabilities and bandwidth of a network. Chapter 2.2.3 remarks establishing ways to automatically process of raw sensor data has been studied by previous researches. Limitation of storage can be alleviated with public or private clouds.

## 4.1 Semantic Web Technologies

Resource Description Framework is a data model for interchanging web-based information. All of the members in RDF represents as triples and each triple might have connected to other triples. As understood from its name, it is a framework for supporting resource description and metadata in the Web. First RDF version provides a set of features that can be used interoperably with the extensible markup language (XML). The authority of W3C controls RDF specifications in terms of update and maintenance of new requirements<sup>3</sup>. RDF consists of several types of models that currently used in industry. The central part of an RDF data is a prefix so-called International Resource Identifier (IRI)<sup>4</sup>. Resource Identifier is rarely not feasible to every generated document from an extensible markup language. The primary purpose of the Resource Description Framework is to integrate data into the web. Algorithmic representation of RDF is a graph data structure, which has a set of vertices and edges. Graph traversal algorithms such as Breadth First Search or Depth First Search allow navigational movement of RDF<sup>5</sup>. A fundamental property of RDF data that navigates internal structure with IRIs

Serialization stands for converting an RDF Format to another to use a variety of syntax notations so that the particular encoding can produce a variety of triples. After serialized an RDF resource, one can obtain the following formats. The consortium named World Wide Web (W3C) inspect RDF Serialization format observing the following goals<sup>6</sup>:

- All rules should be integrated smoothly to RDF
- URI Abbreviation should comply with namespace rules
- Repetition of another object for the same subject should be divided with special Unicode characters
- All languages need to be readable, natural and extendible scope of languages

**Turtle:** Besides being a reliable alternative for RDF/XML, the syntax of Turtle Semantic is similar to SPARQL queries. Turtle Notation is a compact and clear structure. Predicates and subjects can be marked as block

---

<sup>3</sup> [https://www.w3.org/standards/techs/rdf#w3c\\_all](https://www.w3.org/standards/techs/rdf#w3c_all)

<sup>4</sup> <https://www.w3.org/TR/2014/REC-rdf11-mt-20140225/#introduction-1>

<sup>5</sup> <https://www.geeksforgeeks.org/graph-data-structure-and-algorithms/>

<sup>6</sup> <https://www.w3.org/TeamSubmission/n3/>

**Notation 3:** N3 triples are similar to Turtle RDF unlike it is supporting underscored namespaces. N3 triples syntactically is a subset of Turtle RDF because it was designed to be a simple format than Turtle RDF. As much as there are similar syntactic definitions, a variety of differences unlike Turtle RDF has been observed. Triples follow the pattern “subject-predicate-object” and terminal notation. Notation 3 has enlarged grammar structure with extra features more than Turtle RDF and NTriples.

**N-Triples:** Parsers and serializers can easily parse this format because of simplicity. There are no complicated grammar rules with N-Triples, but it is not a suitable format as human-readable. N-Triples has a trade-off to increase machine readability over human-readability. The most straightforward triple statement is a sequence of subject-predicate-object containing white spaces and dot-separated values. It has a tedious format has not abbreviation feature that makes hard to read by humans.

**JSON-LD:** To provide a lightweight linked data format, objects should be converted as a human-readable format. This format is a compact format that has compliance with JSON data. JSON-LD format has a compact dependency on JSON format and it can be used without prior information about RDF. Typically, JSON-LD contains the same structure as compared to RDF like primitive types for nodes and IRIs definition for edges. Standard parsing methods for JSON can be used for JSON-LD interchangeably.

//Explain types, aliasing, nesting, language

**Web Ontology Language (OWL)** stands for Web Ontology Language represents a clear and compact way among relationships of data. Prefixes with IRI is one of the fundamental structure of OWL linked data. OWL can define a class to provide abstraction within the same linked data document. OWL definition is a standard with a Prefix IRI such as “<http://www.w3.org/2002/07/owl#>”, and it is a mandatory field to define if an OWL source used in a linked data. This ontology language leverages RDF Schema to identify complex knowledge requires complex properties [48].

//What is the benefits of OWL – Why did they invent it?

**SPARQL Query Language:** The SPARQL Query Language is a specialized query language by using a particular protocol endpoint for performing data manipulation from RDF datasets. RDF has a collection of graphs, and these graphs are directed and labeled. As a result, triples of graphs can be obtained with a query language from databases or files. The structure of SPARQL resembles Structured Query Language (SQL) very much,

but the SPARQL was designed using for semantically structured triples, not for relational datasets. Additionally, SPARQL is a definition of a protocol working with HTTP Request by defining “User-Agent”, “Content-Type” and “Schema”.

PREFIX, SELECT and WHERE are three basic operators of SPARQL Protocol. PREFIX makes the serialization steps easier referencing IRIs. Prefixes are used for abbreviating of IRIs in a query. “SELECT” and “WHERE” statements used to find the location of objects. IRIs has a wider range of characters to be used in order to accommodate a wider range of languages than URIs [49].

Mainly, SPARQL Requests characterized by Remote Queries or Native Queries. Remote Queries define as sending a query against a remote SPARQL endpoint. Remote Queries needs an endpoint definition provided by Linked Data Source. As for Native Queries, they work mostly in a local database such as graph databases or files and require a query processor to carry on a query against local sources.

The SERVICE keyword reduces the complexity of queries and hands the complex query duty over the SPARQL Service. Real Time Data Annotation Service “KVIN” uses this keyword to prevent making a complex annotation by users.

Sometimes one needs to fetch multiple values in one single query with integrity known as Federated Query. UNION statement can help at this situation to provide federate property into queries. What can be clearly seen is the working principle of UNION is similar to Outer Join in SQL. It takes all Cartesian Product Multiplication, so one can state that the result of an answer impact issue of redundancy. To reduce redundancy, the UNION can be used with an OPTIONAL statement or query can be optimized with only an OPTIONAL statement. OPTIONAL used for allocating a particular portion of SPARQL into results of triples. OPTIONAL reduces redundancy of data and gives every match in any triples. It is a common usage OPTIONAL query with FILTER that allows measuring up a couple of criteria.

One of the most significant problems is searching with blank nodes among triples without clear IRIs information. A generated Turtle RDF can define blank nodes that have no clear identification whilst using with a SPARQL query. To solve this problem, an RDF file can be pre-processed assigning with a traversed property. A traversed property is a linkage between two properties to connect triples each other.

As shown in Appendix A-Listing 0.2, meaningful predicate names are crucial steps to employ with SPARQL queries. Converting from natural language question into triples,

verbs often are mapping into predicates. Predicates are also edged labels that connect two nodes in the graph data structure. A missing predicate of a node stands for a blank node. A blank node is one of the evaluation methods whilst creating semantic data. Although a blank node is not a single evaluation method theoretically, nevertheless it is an essential measurement to evaluate for applicability of question answering with semantic data. Unknown namespace

In this study, SPARQL queries used with Turtle Data Source. The following SPARQL query has been used to fetch triples from generated data.

```
""" SELECT DISTINCT ?property
    WHERE {
        ?s ?property ?o .
        OPTIONAL { ?s ?p rdfs:label. }
    }
"""
```

Listing 4.1: Sample SPARQL against a generated local source

### 4.2 Data Preparation for Heterogeneous Data Source

Most of RDF Sources in the web has typed with RDF/XML. RDF/XML was a step from XML language to RDF, and it has not even namespaces that are vital roles of semantic data. XML Schemas are other problems because of complex encoding and enlargement. In XML or XML-based documents such as RDF/XML, all items have strong hierarchies; hence, this leads to massive parsing overload.

On the contrary, RDF has collections of relations to traverse inside of documents or through documents in an efficient way. When creating an XML from OPC UA Server, the first task should be converting of namespaces. With browse name property of namespace, all initial base of nodes is inserting in an XML document. The second task is to browse among nodes with references and node ID. Display Name and Description will be inserted under OPC UA Objects or Variables in the XML Schema. References are converting as a sub-element of UA. Values of Variables used for an object in semantic data such as Turtle RDF. While sending a SPARQL Query, a query attempt to obtain are using values to give a result to the Semantic Question Answering. XSL Transformation Language can be used for serialization from XML to RDF. As shown in Figure 1.1, the

algorithm of extraction from OPC UA Address Space has been defined as a flowchart. Once a node list defined by OPC UA Address Space, all node-ids and namespaces might be saved into the list.

//Explain algorithm briefly

//Serialization of the Streaming Data

Continuous sensor data should be converted instantaneously into semantic data to be utilized with a SPARQL endpoint. Chapter 2.2.3 examines a couple of studies on how to accomplish with dynamic data. Mainly, one of the ways is extracting all RDF continuously and store into a non-relational database such as MongoDB<sup>7</sup> or NoSQL<sup>8</sup>

As shown above Figure 4-5, a generated file was obtained from eniLINK without making extra IRI processing. Lack of clearly defined IRI complied with eniLINK, it is partly useful to send a SPARQL query with Semantic Question Answering.

This thesis utilizes an API that has implemented as a service known as KVIN to send a SPARQL request into a specified endpoint. This service is an internal development that is based on a combination of a triple store (RDF4J) and a key-value storage library named LevelDB compatible with time-series data. Continuous SPARQL Service was examined with Chapter 2.2.3 which analyzed reviewing past literature with architectural differences in the market. KVIN is a streaming data service that holds limited annotated linked data so that we could use streaming for fast prototyping. Annotated sensor data used for the semantic question answering system. Due to data scarcity, our functions of question answering is limited; however, the platform proves any system utilizes natural query to get semantic data. Instead of using a continuous SPARQL language, KVIN is mapping semantic data with properties internal structure. A namespace is added in KVIN Service for the sake of clearness to convert easily SPARQL triples. To send a SPARQL query, a system requires an endpoint, e.g., "localhost:10080/sparql". A SPARQL endpoint process a request on HTTP protocol that is wrapping up SPARQL protocol that verifies the structure of query as syntactical correctness. Syntactical correctness has provided by a SPARQL validator so that a SPARQL endpoint should have a validator. In the practical work, the architecture of Semantic Question Answering uses SPARQL Endpoint with validator but the query is not sending with the address of the

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<sup>7</sup> <https://docs.mongodb.com/>

<sup>8</sup> <http://nosql-database.org/>

endpoint. Instead of direct-endpoint setup, KVIN tool uses a testing framework “Selenium” with Python language to get triples. A sample SPARQL as shown below:

Relationships with other components of KVIN can be observed as below in Figure 1.1 “General KVIN Service”. KVIN Architecture maps the continuous values onto graphs in linked data. Then, Key-value graph databases to connect the nodes each other through properties. Unlike relational and hierarchical databases, there is no primary key or parent nodes relationship between objects. Nodes might have properties and relationships to traverse from a start node to the end node. The execution time of a query increases proportionally according to size the path of traversing not all size of a graph in the store. This is one of the biggest advantages of a key-value database over relational or hierarchical databases. KVIN SPARQL Service has a strong relationship between Linkedfactory service which are continuous data provided by devices.

```
//Talk about KVIN Influx DB
```

```
//First – InfluxDB – time series to key-value mapper – LevelDB -- KVIN Service
```

### 4.3 Natural Language Understanding

The Natural Language Processing has two subsets, which are Natural Language Understanding and Natural Language Generation. Natural Language Generation is a concept to create from a language description to another description that may constitute a set of formal rules, rules of syntax and semantics. For instance, a machine translation system provides a language exchange interface to perform a set of linguistic rules by words and sentences in transforming into another language. The scope of this work does not address Natural Language Generation; consequently, this work examines methods of Natural Language Understanding.

Natural Language Understanding has a crucial role in Human-Machine Interaction Systems. It enables computers to understand a natural query or voice input without formulating any computer language in the form of binary representation and for computers to allow communication with humans with their language. In this thesis, varieties of methods have been used to extract morphological elements of sentences and identify the main items of natural queries.

Natural Language Understanding starts examining a corpus. A corpus stands for the body of texts or collections of documents. Multiple sources of collections named corpora [50]. Generally, restricted-domain question answering works with collections of texts can be from books, manuscripts or offline-scripted sources such as electronic publications. A question answering system that works under a restricted-domain should be good at making clear the complexities of natural language word-sense disambiguation by using methods of natural language processing.

The methods of Natural Language Understanding has to understand these texts to conclude the language of machines. This thesis uses general methods of Natural Language Understanding with Semantic Data Sources. Characters of data sources do not change the result of knowledge-extraction except the methods.

Statistical Natural Language Processing explores a statistical and model-based approach with corpus-driven data sets. This study will use main methods of NLP such as Part-Of-Speech Tagging, Syntactic Parsing and supply supervised learning methods such as SVM and Logistic Regression in terms of question classification.

We have listed necessary statistical methods as following:

**Stop word removal** is one of the most common tasks in NLP across different implementations to simplify the input structures given a set of rules for stop-words. Stop-words have a different and unique aspect of every language, so libraries of NLP should provide a new stop-word list in every different language. For example, NLTK has a large of the list for stop-words while using the English Language so that this could bring the NLP a drawback that makes usability lower stop-word sources from one language to another. //Preposition and determiner should be removed

**Language Modelling** defines the overall performance of natural language processing methods. Different types of applications that benefit from natural language processing utilize n-gram language models such as spelling correction, machine translation or speech recognition. N-gram defines the size sequence of a given input. For instance, one can tokenize "Could you give me the average value of sensor1 in machine1?" as "Could you", "give me", "the average", "value of", "sensor1 in" "machine1, ?". Therefore, we can call the gram model as mentioned earlier as bi-gram modeling. Because every output of tokenization is parsed as a two-word sequence. N-grams does not only parse inputs with sequences but also it calculates the probability of each sequence. N-gram defines

the scope of analyzation to given a specific language. For instance, if an application requires deepest language property, a natural language system should parse as small as possible to model sequences. Unigram or bigram could take more time for modeling then more significant scope needs.

$N = 1$  (Unigram) has 20000 parameters in order to so. Respectively,  $N = 2$  (bigram) has  $20000 \times 2 = 400$  million,  $N=3$ (trigram) has  $20000 \times 3 = 8$  billion, and  $N = 4$  (four-gram) has  $1.6 \times 10^7$  (referans gerekebilir). Apparently, the more n-gram model we have, the more complex system a question answering system or natural language processing tool need to solve.

Furthermore, an input can be dispersed to more substantial sequences, but the context of modeling would be messy. So one can say that language modeling is very relevant to application-specific. By using the chain rule formula, the n-gram model predicts the conditional probability of the next word [51]. As depicted in Figure 5-1, language modeling can be estimated with Maximum Likelihood Estimation.

$$P(w_n | w_{n-N+1}^{n-1}) = \frac{C(w_{n-N+1}^{n-1} w_n)}{C(w_{n-N+1}^{n-1})}$$

Figure 4.1: Maximum Likelihood Estimation [51]

For instance, “I would like to know where the error is. “ represents a probabilistic method as Maximum Likelihood Estimation with  $P(\text{"I"}) \times P(\text{"would"} | \text{"I"}) \times P(\text{"like"} | \text{"I would"}) \times P(\text{"to"} | \text{"I would like"}) \times P(\text{"where"} | \text{"I would like to know"}) \times P(\text{"the"} | \text{"I would like to know where"}) \times P(\text{"error"} | \text{"I would like to know where the"}) \times P(\text{"is"} | \text{"I would like to know where the error"})$ . The main problem of this approach is to calculate the long-chain probability of total length. As the size of the sentence grows, a system needs more processing time for the calculation of probability.

On the other hand, the Markov Model can say the last few words affect the order of the next few words. Markov Assumption interests  $n - 1$  number of words in an n-gram model, but this assumption does not concern from that further. N-gram language models help the creation of corpora. While creating a language model, testing and training data sets evaluate the correctness of language model. In the practical implementation, libraries assess the corpora through the n-gram model so that the libraries can produce better results in the statistical natural language processing.

Therefore, the next question is about natural language processing how to evaluate n-gram language modeling. Extrinsic and intrinsic evaluations mainly used in the phase of evaluation for language modeling [51]. The external evaluation stands for end-to-end testing by performing all the system functions over again. For example, if we want to assess the performance of a language model in a software library, the system can be performed multiple times to see the results. However, it takes enormous time when a corpus is big enough especially, four-gram or further. Intrinsic evaluation separates the data set into a training and test set.

**Perplexity** theory implies test set tells how the given model predicts the results well. The more results truly predict the lower perplexity a natural processing system can get. The lower perplexity denotes a better model. As shown in Figure 5-2, perplexity shows an inverse probability of a model. At some conditions, dividend goes to zero value in case that a test set could not be matched in a training set. In this case, perplexity cannot be evaluated. Additionally, a machine learning approach always suffers from overfitting issue. If a training phase have occurred more than average, a system would not give the right results given a test set and behave like generalizing every test set.

$$PP(W) = \sqrt[N]{\prod_{i=1}^N \frac{1}{P(w_i|w_{i-1})}}$$

Figure 4.2: Perplexity formula of a language modeling [51]

**Normalization Process:** Normalization used for eliminating frequent low-level usage of the words with regards to applications. Unnecessary words are supposed to be eliminated seeing the way clear to making a less-overloaded application. Every corpus or any data sources should be refined before a process has implemented in natural language processing.

**Stemming and Lemmatization** are normalization steps that cleanse unnecessary prefix, suffix or other morphological appendixes. Subject-predicate-object should map onto noun-verb pairs in order to create a SPARQL query. If a predicate has a prefix, e.g. "If:contain", given verb are cleared surpluses by implementing a lemmatization.

Usually, stemming can cleanse suffix, prefix or influx from nouns to reach the pure version of a word. However, a restricted-domain question answering has individual words with suffixes that can have a different meaning for the system, or these special words can belong to a different hierarchy of a tree. So a lemmatization and wordnet synonym analyzation have been enforced on verbs.

**Part of Speech Tagger:** A sentence consists of a couple of structure including words like noun, verb, pronoun, preposition, adverb, conjunction, participle and article that are main categories of part of speech processing [51]. Part of Speech Tagger mostly uses a Markov Model that is a part of statistical natural language understanding. Markov model stands for a state can depend on a previous step, but there is no dependency on states of historical steps more than one. For instance, a noun or a verb tells us about its neighbors, e.g., nouns are preceded by determiners, adjectives, verbs [51]. For example, a chess player makes a movement according to the last movement of a rival rather than guessing from the first movement of the rival. In this step, pre-saved corpora which has a million words has to be tagged by POS Taggers. One of the common list that has an identifier for POS named as Penn Treebank. A treebank used for annotating syntactic and semantic structure of a sentence with million words of part-of-speech tagged text. Selection of a corpus equally important to achieve a result with a parsing process.

A major concern of the Penn Treebank is to provide multiple syntactic bracketing if necessary [52]. Multiple brackets are important for example Brown Corpus tags “one” and “the one” as Cardinal Numbers but it “the one” case could be an important determiner in any sentence. Every tagger named as labels, which are clause level, phrase level, and word level taggers. However, it is important to annotate as a common noun (NN) for detecting the head of a noun phrase in a sentence. So “the linkedfactory” and “linkedfactory” are assigned as a common noun or an adjective phrase but those could be identified differently with tagger according to Markov Model of the item in a sentence.

The simplest tagger uses a method called by NLTK library as NN\_CD\_Tagger which assigns a tag to each token on its basis type but it has a quite low performance because this method is tagging only as Noun Phrase(NN) and Cardinal Numbers(CD) [53]. A sequential tagger could give us a better performance such as Unigram and N-gram tagger.

**Parsing:** When a natural query is given, a question answering system should understand the grammar behind it. POS tagger is not enough to identify a grammatical structure for complex natural queries. Relationships among noun phrases, adjective phrases, adverb

phrases, and verb phrases should be examined in order to map subject-predicate-object triples correctly in linked data. The approach of parsing separated into two main sections, which are the rule-based approach and the probabilistic approach [54]. The rule-based approach is a top-down approach to solve problems via predefined rules such as the way of Regex-parsing. Therefore, a question answering system should define rules precisely to get the correct answer. Open-domain question answering systems use this approach because of the complexity of the bottom-up approach and broadened question types. Nevertheless, a rule-based approach could give undesirable results in restricted domain question answering or semantic question answering and could be time-wasting parse approach. The probabilistic

Syntactic parsing commences parsing sentences with chunking that is a shallow parsing without analyzing the deepest node of the parsing tree. Items can be assigned as a noun phrase and a verb phrase. In our case, this method could be practicable, for instance, “linkedfactory” keyword might be combined as an adjective “linked” and a noun “factory”. If the parser went into the most rooted leaf, it would have been relatively faster operation.

Various types of probabilistic parser have been prevailed since the natural language processing research started. It depends on the grammar of the English language and how much profoundly information source that required by a question answering system. Formal Grammars of English defines a constituency parse approach, which can identify noun, verb or adjectives in a big chunk like shallow parsing. This approach eliminates of item relationship among nouns, verbs, and adjectives by providing an abstraction method. If a question answering system needs a relationship between subjects and objects, a constituency approach is not suitable to utilize because of shallow parsing. In the case of syntactic parsing, the task of recognizing sentence and its grammatical structure [51]. Syntactic parsing suffers from “*word-sense disambiguity*” problem. This problem denotes that a word can represent different meaning in the sense of location in a sentence. For instance, “*What does linkedfactory contains*” could be differentiated “*Could you give me the members a factory which has linked?*”. Both sentences are semantically similar but hard to recognize by lemmatization and sentence similarity methods.

The method in practical implementation is partial parsing known as chunking. Parsing can check the grammar of language according to correctness. Handling the ambiguity better, the system utilizes a probabilistic parser provided by Stanford Core NLP, Spacy, NLTK, Textacy, and TextBlob libraries.

**Syntactic Parsing:** This is the stage of recognizing the syntactic structure of inputs (sentence, keywords) using shallow or deep parsing.

**Dependency Parser and Constituency (Syntactic) Parser:**

//Explain Parsing with mathematical methods

**Spell Checking and Abbreviation Correction:** Spell checker is an evaluation criterion for restricted question answering system. It is not necessary to provide advanced spell checker controlling all aspect of morphological, semantical and syntactical rather preferring at least a simple checker. Industrial based spell checker is hard to implement due to some restrictions such as ... .

As for abbreviation correction, it is difficult to find an acronym because of punctuation at the end of the acronym. Domain dependency could be another issue such as computer science, medical, or currency domain. Types of domain mainly used in open-domain question answering system due to a variety of questions. To infer an acronym, a system expects to utilize a well-formed dictionary overlapping the domain of semantic question answering. A smart factory entirely has different vocabularies and acronyms than a medical domain. In this case, the best way to classify accurately an acronym using a simple look-up dictionary or hash table. A Bayes Theorem and Levenshtein Distance Algorithm would be useful to find both on spell correction and abbreviation checker. However, the spell correction gives better results than the abbreviation checker does under the Bayes Algorithm (given a result set)

**Named Entity Recognition:** It is a subtask of information extraction to locate and distinctively named entities with pre-classified labels such as names of people, organizations, locations, quantities, etc. Named-entity recognition is a method that identifies the item of a sentence as a domain-specific. It defines all structures mainly as a person, a location, an organization, and an entity. As shown in Figure 5-3, “sensor1” and “machine1” named as an entity and found a relation between each other. Unfortunately, the named-entity recognition of Stanford CoreNLP could not identify an entity as person or organization presented by AllenNLP as depicted in Figure 5-4.

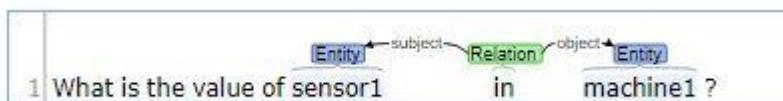


Figure 4.3: Named-Entity Recognition by Stanford CoreNLP



Figure 4.4: Person and Organization assignment by AllenNLP

This evidence shows us named-entity recognition is an application-specific task. An NER Method that is created for a different domain may not be reused for another domain. To create a named-entity recognition for a smart factory, a model can be trained to satisfy the requirements of a smart factory. In this context, a model can be created by statistical methods or a rule-based model. In context with the rule-based model, the character regex method can identify the structure of a natural query. For instance, a named-entity recognizer can employ a model that contains a combination of "Heat-Meter" or "HeatingWater", which it can assert given items with the character started by "Heat" in a smart factory. [Open Domain Question Answering](#)

**Word Vectors (Word2Vec and Glove Data):** Words can be represented as vector spaces. One can create the meaning of words table by converting a word into a vector. For instance, if we discuss two main phrases such as "*internet of things*" – "the network of physical objects with electronics, software, sensors, and connectivity", "*Mesh Network*" – "The topology of a network whose components are all connected directly to every other component", these two phrases similar in terms of frequency matrix of their meanings. "connected" and "network" are equal semantically. Therefore, one can create a word vector from corpora in order to identify word similarity. Due to the data size of corpora, a word vector can reduce the feature space of corpora.

**Sentence Similarity:** Sentence similarity used for comparing two string inputs in order to achieve indicative questions like "Is the system health good?". Mainly, this method leverages averaging word vectors such as word2vec or glove implementing Euclidian and Manhattan Distances or Cosine Similarity algorithm. In order to calculate distances of word, n-gram model or more specifically bag-of-words concept can be implemented. It is a subset concept of n-gram modeling. In practice, every single element is assigned into an array, for instance when comparing the following sentences:

"Is the system health good for sensor1 in machine1" and "system health status sensor1 machine1"

`BagOfWords1 = {"Is":1, "the":1, "system":1, "health":1, "good":1, "for":1, "sensor1":1, "in": 1, "machine1":1}`

`BagOfWords2 = {"show":1, "the": 1, "system":1, "health":1, "status":1, "sensor1":1, "machine1":1}`

`Vector1 = [1, 1, 1, 1, 1, 1, 1, 1]`

`Vector2 = [0, 1, 1, 1, 0, 1, 0, 0, 0]`

Vectors scored as binary whether a word is the same with its counterpart or not. In most cases, this sort of evaluation is unpractical because semantic structures of words are not taken into consideration. Therefore, the following methods can precisely calculate the word similarities of vectors can

**Jaccard Similarity:** This algorithm uses a procedure to calculate the similarity between sets of data defining as the size of intersection divided by the size of a union of two sets [55].

$$J(A, B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|}$$

Figure 4.5: Jaccard Similarity Formula [55]

**Jaro Winkler:** This algorithm calculates transposition of matrix t, and the number of common characters by putting into a formula as below:

$$sim_{jaro}(s_1, s_2) = \frac{1}{3} \left( \frac{c}{|s_1|} + \frac{c}{|s_2|} + \frac{c-t}{c} \right)$$

Figure 4.6: Jaro Formula [56]

The Winkler algorithm increases the Jaro similarity employing initial characters and gives a similarity measurement [56]. For example, Jaro Winkler takes head characters of a string such as “health” and “heal” to perform the Winkler formula.

**Levenshtein:** Levenshtein algorithm has a variety of application areas such as spell checking, acronym finder or sentence similarity. This algorithm calculates cosine distance of given two strings and divided by the maximum value of absolute value of given two strings.

$$sim_{ld}(s_1, s_2) = 1.0 - \frac{dist_{ld}(s_1, s_2)}{\max(|s_1|, |s_2|)}$$

Figure 4.7: Levenshtein Formula [56]

**Wordnet Analysis:** Wordnet is one of the largest databases for English lexicon that can be used for word and sentence similarity analysis. Depends on the domain of question answering, Wordnet Analysis could be used for sentence similarity or verb-noun analysis. In essence, it is a combination of two major algorithms known as Wu-Palmer Similarity and Leacock-Chodorow Similarity.

**Wu-Palmer Similarity (wup\_similarity):** This measure calculates relatedness by considering the depths of the two synsets in the WordNet taxonomies, along with the depth of Least Common Subsumer [57]. With the following formula as shown in Figure 5-7,

$$\delta_{\text{Wu\_Palmer}}(c_p, c_q) = \frac{2d}{L_p + L_q + 2d}.$$

Figure 4.8: Wu Palmer Formula [58]

After defining Least Common Subsumer, which is a tree-based semantic relatedness measure extracting from “is-a” relationship of a tree. For example, “contain” and “incorporate” synsets are identical according to Wu Palmer algorithm. First of all, WordNet finds the first Tree with categories like [57] :

```

1) Tree1 = ROOT → Include → Contain
2) Tree2 = ROOT → Include → Incorporate
3) Least Common Subsumer(s) = argmax(depth(subsumer(Tree1,
    Tree2)))
4) Depth of Least Common Subsumer = depth(*ROOT*) = 1
5) Depth1 = min(depth({tree in T1 | tree contains LCS})) = 3
6) Depth1 = min(depth({tree in T1 | tree contains LCS})) = 3
7) Score = 2 * Depth of Least Common Subsumer / (Depth1 +
    Depth2) = 2 * 1 / (3 + 3) = 0.3333333333

```

Listing 4.2: Wu Palmer Sample Calculation[57]

**Leacock-Chodorow Similarity** (lch\_similarity): This algorithm is very similar to the Wu-Palmer Algorithm except it calculates a negative logarithm of the path similarity. Let's give the same example comparing to "contain" with "incorporate":

```

1) Tree1 = ROOT -> <include> -> <contain>
2) Tree2 = ROOT -> <include> -> <incorporate>
3) Lowest Common Subsumer(s) = argmin(length(subsumer(Tree1,
    Tree2)))
4) Length(incorporate) = 1 and MaxDepth (v) = 14
5) Score = -log(length(Lowest Common Subsumer)) / (2 *
    max_depth(LCS.pos)) = -log( 1 / (2 * 14)) = 3.332204510175204
    > lch_threshold (equal to 2.15)

```

Listing 4.3: Leacock-Chodorow Sample Calculation[57]

**Question Classification:** A question answering system regardless of domain type needs a question classification algorithm to choose the best answer match. There are a couple of methods based on logistic regression and support vector machine that a question classification can use.

**Logistic Regression with newton-cg:** Logistic Regression is a predictive analysis method that uses a binary classification method wrapped the combination with range [0, 1].

**Logistic Regression with lbfgs:** Limited Memory BFGS is an optimization algorithm of Newton-methods. We should understand what the Broyden-Fletcher-Goldfarb-Shanno method is

**Logistic Regression with Cross-Validation:** To classify more than one categories, multinomial logistic regression method. Regression models are useful for continuous data; however, can be used when required a categorical dependent variable. Cross-validation defines the same data set as training and test data.

**Linear Support Vector Classification:** Support Vector Machine is a type of supervised machine learning which has two advantages over the regression methods. Firstly, SVM creates high generalization performance in high dimensional features. Secondly, SVM can manage a kernel function without affecting the computational complexity in higher dimensional features. If the kernel function is a linear function, SVM turns out to be Linear Support Vector Machine.

#### **4.4 Chapter Discussion**

//Natural Language Understanding Discussion

//Serialization Discussion with semantic technologies

//Infer a message to research question and hypotheses

Serialization from one to the other always has overhead for designing an architecture. The Resource Description Framework complies with the requirement that streamed data or generated data by an OPC UA Server. Nevertheless, the extensible mark-up language is an intermediate processing between a generated data and the resource description framework. As understood from testing of XSL Transformation, an address space of OPC UA that has complex structure and massive amount of data may not be a convenient way to serialize. Moreover, a serialization step could take time proportionally the size of data, which a server consider that regarding client connection could not respond back within the session timeout of the server. This leads to a serialization failure and the step may close the connection silently. XSL Transformation requires the extensible mark-up language format from an OPC UA Server and the tool starts from scratch when a request sent by a client with regards to serialization between XML and RDF. Luckily, an OPC UA Server can assure the language compliance, but it may not intervene the process of serialization. Hence, an OPC UA Server shall not take into consideration the small changes such as monitorable values, which it could cause a large repercussion in the serialization of hierarchical structure in the server.

Streamed Data Serialization may take benefits from either C-SPARQL, Instant Semantic Source Creation or Key-Value Mapping. KVIN Service follows key-value mapping that has the lowest overhead while performing against SPARQL Endpoint. However, limited description with linked data and extendibility of a substandard of SPARQL might have occurred. C-SPARQL. Key-Value Mapping is a quasi C-SPARQL solution, which the KVIN has a specified window size to collect data within a range of time.

As a result, combining static and streamed data as linked data source is the best way of representation and tackling the problem as a whole. Due to complexity of design, it is not possible to create such application without a large of effort. On the one hand, detaching static and streaming data serialization step would be beneficial if we want to reduce the graph size for traversing. On the other hand, describing a natural query regarding streamed data or static data is a difficult problem to solve so that we should a further step of natural language processing tool that distinguish the query related to which one.

//Be specific

//Be specific

//Be specific

//Connect to the research questions. More general

## 5 Practical Implementation

### 5.1 The Architectural Design of the Web-Based Software

Scalability, mobility, and ease of use are substantive elements of web architecture for a web-based software application in smart factories. Generally, applications that have targeted particular tasks are having a tendency in developing as desktop applications or built-in applications of embedded systems. This type of use reduces mobility for human operators and experts in a smart factory. Hence, a web-based software can be a lifesaver to make the mobility of tasks possible. Whereas, a web-based software cannot be realized without architectural thinking to deploy into a large-scale application. Nevertheless, we should investigate data-intense solutions like the operator assistant web-based software regarding robustness, scalability, high performance and security.

**Architectural Pattern:** The architectural patterns used for connecting different element of web-based software to introduce a user experience to end users. We will give details about the architectural patterns that we have analyzed.

**Monolithic Architectural Pattern:** A monolithic architectural pattern can be composed in a single piece of software. In monolithic architecture, we cannot scale components differently and interdependency of components are more potent than the n-tier architectural pattern and microservice architectural pattern. Deployment is the main feature of a monolithic application. A monolithic application can consist of several services or components but if it only can be deployable into a logical structure as a whole, then we can accept this solution has a monolithic architectural pattern. The most significant disadvantage of monolithic applications is that they might not be usable modular so that one cannot solve the complexity of the code base problem easily. However, the main advantage of this architectural pattern is that developers can develop their application in focusing on building a single application. A monolithic architecture can balance internal services by running several instances with a load balancer.

**Microservice Architectural Pattern:** Microservices are a new design paradigm that has entered to software world by significant features. Deployment may create many difficulties that one has not faced when an n-tier or monolithic architecture. Each service should be small and easy to maintain in microservices. The components of microservices store their data source such as a database, necessary configuration files distinctly. A

significant advantage of a microservice decomposes a whole application into services. This architecture employs lightweight protocol such as REST or Remote Procedure Calls [41].

Although microservices are had advantages over other architectural patterns that have been mentioned in the section, there are several drawbacks that one should consider them. Adoption of a microservice from different architectural patterns, is hard since a system should be separated services and components to minimize in deploying as a microservice. Testing is much harder than others because end-to-end testing and optimal service testing should be considered separately. Distributed applications in microservices may have continuous deployment and broker-based message application to increase deployment and performance features. Such features may cause more complicated architecture when deployment has been initiated.

Microservices decouples the development and deployment process. Such development process could be API development with REST endpoints. For instance, when a developer realizes a web-based software, it would have a dependency from older versions. Older version issue creates a problem for future development. If there is strong communication architecture between components, dependency problem can be enlarged, and the overall system may lose the feature of microservice out. Fault isolation is strong in microservices, which one component does not affect from an external failure as another component has generated.

As a result, the primary principle is dividing the component as much as possible unless it can utilize their data source and internal functions without dependency on other components.

**Distributed Monolithic Architectural Pattern:** This pattern denotes an intermediary architecture between microservices architectural pattern and monolithic architectural pattern. Components of the distributed monolithic architectural pattern may have a dependency on deployment and development. Binary dependency among components is as strong as monolithic architecture so that microservices can be distinguished from monolithic architectures.

Failure can affect multiple components because there might not be a clear separation between distributed components. Distributed components have not well-separated data storage and small units that may be scaled independently without having scaled entire architecture.

**N-tier Architectural Pattern:** Basically, the N-tier architecture comprises presentation tier, application tier, and business tier. Each tier can have multiple layers that can coherently work in a physical system. While a tier represents the physical environment of the architecture, a layer represents more likely abstraction of a tier. Each layer can be a logical organization of the project, which means an organization of code. Layers can connect to each via sockets and sockets are the type of interprocess communication. Layers should be differentiated using multiple sources in tiers. However, there is no need for strict separation for tiers. For instance, operating systems such as Linux and Windows can transfer messages through shared memory. However, the conventional view of architecture represents a single tier.

The Presentation Layer displays information related to incoming requests by end-users in having a relationship with the application and data layer. The Application Layer has a core logic of a system the presentation tier is responsible for displaying information to regarding users. It is the last point for all other tiered architecture that introduces the information to end-users. The Data Layer is responsible for containing persistent data in storage. This architecture reduces the deployment cost and easy to optimize in the context of code base. Unfortunately, it suffers from communication points as n-tier architecture increases communication points, which it causes complexity of communication point. In addition, communication parts can share among application layer and business layer so that one can consider that it does not solve separation of layers.

**Service Oriented Architecture:** “Service-Oriented Architecture (SOA) is an architectural style for building systems based on interactions of loosely coupled, coarse-grained, and autonomous components called services.” [42]. Each service discoverable addressed called endpoints and transmitted composed messages to each other [42]. It supports organization of distributed components in a black-box process. This black-box process utilized heavyweight-XML based protocols such as SOAP or Web Service Definition Language. Despite the fact that it provides a decomposing way for organization with a service provider, a service discovery and a service consumer, it is widely thought as a larger monolithic application. SOA supports loose-coupling and service reusability such as Microservices, but there might be data storage could be common storage whereas microservice discriminates data storage to regarding services.

**Programming Design Pattern:** This concept stands for repeatable solutions for common problems that one encountered in occurring issues. Even though there are numbered programming design pattern under several categories, we will introduce some design pattern that we have realized in the following statements:

**Model-View-Controller Pattern** states all parts of software should be dissected separately in having a relationship with the user interface. This pattern decouples the components as model, view, and controller to provide code reusing and separately deployment.

Model encapsulates business logic and data. In computer science, business logic is the part of a program that encodes real-world requirements in terms of creating, reading and updating. All of the items have dynamic nature in an application so that other layer of an application may concern changes that are presented by a model. View demonstrates a view of the modeling of data presented by the same data. It also closely relevant to visualization, beyond that it has a purpose for showing multiple views regarding the same data modeling. The controller acts on both the model and the view. It also copes with data changes and provides an endpoint for a view to visualize data's content.

**Client-Server Pattern:** Client Server Pattern exemplifies that workload can be distributed between service providers and service requesters. Such servers can save states of sessions that have identified by clients or servers purely communicate with clients in a stateless and cache-based way. Servers hold application logic to present information and calculation when a client requested. A client has responsibility for end users since a client can initiate exchanging messages between servers and clients.

Moreover, a client can send a message instantly to servers to check their health status whether a server is in service or out-of-order. This mechanism called polling that can send a message from client to server within a particular time arrival. Two important concepts differ in that respects. Synchronous communication refers to dependent communication respective messages in a blocking manner. Such messages should wait for the next one to complete their operations. One task can execute an operation as soon as another task finishes. Asynchronous communication concerns repetitive or respective tasks should not be aware of one another. For instance, Task A may execute an operation before Task B does, but Task B can respond to the client before Task A finish the operation. In this way, a user can send a request to a web service without waiting for the result of queries. The Asynchronous communication is implementing by multi-thread management, finite state machine or event-based callback functions. For instance, event-based callback functions that script language used is a general type of asynchronous function.

Regardless of being asynchronous or synchronous requests, a question might have asked by readers. How can a web-based architecture adapt to increasing workload? The questions leads us to a concept for distribution of workload via a medium. This medium called load balancer. A load balancer can balance workloads by using the predefined algorithms. In this work, we will use the round-robin algorithm and the least connection algorithm.

**Single Page and Multi Page Applications:** These two programming pattern deeply helpful for developing front-end applications. Single page concept refers to load and refresh all web elements in a web browser during use. It does not refresh entire page but only demanded content. The single page applications can cache local data, which one can load data in case of offline connection. When the offline connection turned out be an online connection, data content updates automatically. The multi page applications update entire page upon each request exchanged between server and web browser. Multi page applications are useful for data driven applications especially like search engine, question answering or database applications. Although it decreases the speed of communication between front-end and back-end frameworks, it increases the scalability regarding requirements of a domain.

## 5.2 Front-End Development

### 5.2.1 Overview

**Angular 2:** Angular 2 is an extension framework that develops a variety of properties of Angular JS. Libraries of Angular 2 are not suitable to work legacy usage, so Angular JS Framework cannot use any library from Angular 2. The main reason for the underlying framework has been written in TypeScript, not in the JavaScript library. Angular 2 has a new command line feature that extracts essential information from “package.json”. All sort of libraries is saved into “package.json” to detect discrepancies between versions of libraries. Angular 2 allows embedding dynamic bootstrapping features into a pure HTML Page. The biggest drawback of Angular 2 is that it is not backward compatible, and the differences between versions can be immense. While Angular JS follows the pattern of MVC, Angular 2 implements a component pattern. Besides, Angular 2 splits component by component to increase code reusability and achieve the object-oriented paradigm in script languages. Angular 2 is faster than AngularJS versions because Angular

2 uses different hierarchical dependency for each module. When a module updated by a developer, only regarding hierarchy updated so that the front-end framework can enhance the running and compilation performance. A developer can use an external asynchronous event library in AngularJS, but Angular 2 provides an internal library implementing an asynchronous feature.

**Ember.Js:** Ember.JS is a JavaScript MVC Framework that helps to organize large web applications. The structure of Ember.js is depend on micro-libraries [59]. MVC pattern fully complies with Ember.Js in terms of bindings, computed properties and automatically updated templates [59]. Bindings enable the change of a variable propagating to another variable. Calculated Properties and Automatically Updated Templates ensure the framework stay up to date with regarding data source of Ember.js. One of the major advantages of Ember.js is Ember Data Library which stores all values of a process by means of caching into an In-Browser Store [59]. Ember.js supports all end-to-end testing tool such as Karma and Mocha. Testability is an important step to develop bug-free codes so that one can state Ember.js has a variety of compliance with test tools.

The main purpose of Ember.JS is to support a Single Page Application; thus it has no architectural layer for server-side rendering. Server-Side Rendering is an old transfer technology for HTML Websites and brings a significant overhead in case of minor changes. In addition, Server Side Rendering works with static sites that need to load the entire structure of web pages. However, the initial page loading time of Server Side Rendering is shorter than Client Side Rendering does. Ember.Js is fully backward compatible that means one can use a function from an old version in a new version.

**React:** The React Framework serves the purpose as a full-viewer of a front-end library. React is primarily concerned with the view aspect of UI and it is not suitable to use as a framework or library in a large-scale application [60]. React does not enlarged support for the following necessities: HTTP Calls, Routing, Dependency Injection are robust components when implementing a Web Service, so React cannot be taken into account a good solution for full-scale web service but the viewer. This could be a big drawback while comparing with AngularJS framework. React has been posited that front-end developers can leverage its features to create the part of a viewer in MVC. React does not follow the MVC Pattern. **More likely known as component-based architecture, it is traditionally different from MVC pattern**

//Component based architecture

//React.js focused on the view of part of the model view controller

**MeteorJS:** MeteorJS is an open source project which has built on a stack of MongoDB, Node.js, Angular, and Express.js have consistent client-server applications, reactive modules, and rapid prototyping [61]. The underlying structure is based on Node.js and its virtual box named Google V8 Engine. The underlying mechanism of MeteorJS detects the changes of the object and automatically set the results before a developer made. Angular2 and React have observables to ensure this set of property.

**VueJS:** VueJS is a frontend framework that has a similar grammatical structure to ReactJS and AngularJS. Templates are one of the powerful features that used by VueJS. Through templates, the VueJS provides data bindings. Templates support two-way data binding, that means when you changed an input, VueJS will update the corresponding element. After combining VueJS element with HTML, every element of VueJS will be reactive, which inputs are rendered immediately accordingly. VueJS is a component-based system that the abstraction mechanism of language works with components. Methods can be called in VueJS through cached memory. Thus, a cached method is not compiled in multiple calls so that a VueJS application can reduce the memory complexity of method calls.

One-way bindings only propagate the changes into one single direction. Two way data binding allows to implement data flows two directions.

### 5.2.2 implementation of FrontEnd Development

## 5.3 Back-End Development

### 5.3.1 Overview

Main features of ASP.Net Core used with Controller in this thesis and the Controller base class for an MVC Controller with view support<sup>9</sup>. ASP.NET Core MVC has model binding, routing, dependency injection, filters model validation.

In this work, synchronous communication for a web user to get a JSON Web Token authentication access. When a user has the right access, all requests are sending asynchronously. Due to the nature of JSON Data parsing and Publish / Subscribe architecture, the usage of asynchronous requests are necessary for the return of requests interior architecture.

Selection of the back-end and front-end libraries might have changed according to the requirement of a web project. In fact, different versions of a framework may create different results under certain and same test conditions. However, Chapter 6.1.4 indicated to which one displays the best performance and worse performance. Rather than comparing the performance of front-end framework, Chapter 6.2 explained the script languages and front-end frameworks in terms of modular applicability, loose coupling, and scalability. Using software development kits can improve the quality of an OPC UA Software because of the difficulty of writing an OPC UA Stack.

The following section is a brief description of the back-end development process in terms of a framework that has used in experimental development of OPC UA, Information Model Mapper for Semantic Data and Semantic Question Answering. All of these development cycles are examined with a comparison between frameworks, languages, libraries and toolkits. Regarding OPC UA Web Application, frameworks, languages, and soft-

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<sup>9</sup> <https://docs.microsoft.com/en-us/dotnet/api/microsoft.aspnetcore.mvc.controller?view=aspnetcore-2.1>

ware toolkits are taken into account. As far as Semantic Question Answering and Address Space Extractor of OPC UA will be taken into account libraries and their performance. Software Development Kits was split up open source and commercial kits due to licensing co

**ASP.Net Framework (Active Server Pages .NET):** ASP .NET Framework one of the oldest framework used by developers to implement web applications. The oldest framework named as ASP.NET Web Forms. ASP.NET Web Forms was strongly dependent on the Windows Operating System because of Internet Information Service (IIS). This server used for deploying web applications that can work only within the Windows Operating System. Moreover, this framework was limiting changes due to an internal file of the Windows Operating System as known as Web.dll [62]. Web Forms evolved to ASP.NET MVC Framework to comply with Model-View-Controller design pattern.

**ASP.NET Core:** Besides the continuous improvement of this technology, Microsoft Company decides to scale this framework Unix-based architecture. Therefore, the name of the technology changed as ASP.NET Core, which brings to the developer worlds lightweight features. One of the most prominent features of ASP.NET Core is the routing framework to control Rest API calls. When an HTTP call arrives, it should be parsed as a schema and host path. Schema path decides which protocol used an underlying structure to deploy a call. An aspect of the query string to understand specific element, the host part contains path and query structure to discriminate an HTTP call from each other. ASP.NET Core mainly used for a production environment because of the immature step of development like ASP.NET Framework (Think about). To deploy a web application rapidly, ASP.NET Core is a better choice thanks to its lightweight functions, the code size of the virtual machine, open source code, and interoperability with Unix-based operating systems. Moreover, ASP.NET Core has legacy support with ASP.NET MVC and Web Forms so that the framework can extend internal functions with legacy projects.

**Node.js:** Node.js is a framework based on JavaScript language that leverages a virtual machine developed by Google Inc.<sup>10</sup> Node.js is an event-driven server-side development framework. By leveraging a virtual machine named V8 Engine, the framework sends an event signal to the virtual machine rather than communicating an operating system itself. Node.js has a broader support for multiple operating systems because the virtual

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<sup>10</sup> [https://www.w3schools.com/nodejs/nodejs\\_intro.asp](https://www.w3schools.com/nodejs/nodejs_intro.asp)

machine has been compiled for multiple targets. Not only the framework is compatible with a client-side script language, but also it can integrate callback functions with low-level compiled language such as C++ or C. This paradigm had named as Native Call in the software world that is very useful when a function result returned from a programming language managed by a virtual machine into a native language. A finite state machine implemented by C++ creates asynchronous callbacks until a garbage collection eliminates the objects of callbacks.

**Java Spring Framework:** Java Spring Framework is the closest architecture to ASP.NET Core in terms of package management, virtual machine based garbage collection, routing and dependency injection. It has an object mapper such as Entity Framework in ASP.NET Core that ability to connect with databases mapping object into database objects. By supporting modular development, the code can be split into modules and it is getting easier to handle with code size when a project source code's volume (size) increased. Spring Framework work with Plain Java Objects.

**Flask Micro-framework:** Flask is a micro-framework using by many software developers benefits of rapid prototyping. For the reason that we need to develop a rapid-prototyped solution, Flask helps developers in many aspects. The Flask is working with many versions of Python 2.x and 3.x. There is no complicated routing mechanism and utterly compatible with microservice development. Annotators are bounded but compact, which is making the learning curve of the framework higher. A Flask Application can ensure JWT Authentication and other security policies with external libraries. In the research phase, we faced that the biggest problem of Flask is a non-asynchronous structure. One of our proposal to remedy the problem is using a non-blocking input-output queue with an asynchronous task queue. A non-blocking input-output queue can create an internal load balancer by balancing all requests into a queue before it reached to the application. It is far more than making a routine asynchronous. When an asynchronous queue works, it selects a message broker to connect a non-blocking input-output queue. This overall system creates an internal “message-broker system”. To change simply version from 2.x to 3.x would be the second solution. Because Flask application does not have the “async” keyword that makes the routines asynchronous call.

**Django Framework:** Django Web Framework is a loosely coupled, high-level Python Web framework along with supporting Model View Controller pattern. It leverages the language property of Python allowing indented programming and implicit data types.

Underlying pattern is a bit different from MVC because the view part could present views through templates. The framework operates across multiple tiers such as Business Logic, Application, and Presentation Tiers. Django uses a particular template to fetch iterative values from template engines, and it is believed that the templates shorten the code complexity of Front-End. Django has a package manager called “pip” to organize libraries in a virtually separated folder. Main issues about Django are not occurring from the architecture of the framework, and rather it is associated with versions of Python 2.x and 3.x creates discrepancies among libraries. Routing Mechanism provided by regular expressions with precedence rules. When an URL is matched, all other requests are dropped in accordance with precedence rules. Django can consolidate URL Patterns by including a URL one into another. In this way, developers can easily manage the URLs and HTTP Requests within a single base URL entry point.

#### //Test sonuçlarını gözden geçir

In the following Table 6-2 (reference Appendix B.6), the thesis examined with a couple of parameters such as Performance with Multiple and Single Queries, JSON Serialization Fortunes etc. It has been referred to platforms, micro-frameworks, and full-stack frameworks as “frameworks” [63].

The test suite provided by TechEmpower [63] contains multiple query tests, single query tests, Plain Text test, JSON Serialization tests. JSON Serialization test includes request routing, request header parsing, object instantiation and representation, the creation of a response header regarding a request [63]. Single and multiple queries sent against the database to test connection pool and performance of input/output given a set of a framework. A simple SQL query is prepared regarding context and header with the aid of an HTTP POST request. Instead of JSON query, a plain text such as “Test Framework” sent by a request header with content through HTTP 1.1 at different concurrency levels [63]. The higher scores of percentages show how a framework perform better under equal circumstances.

In the same way, the latency is a parameter indicating the duration of the delay within consecutive queries. In this test, each request is processed to fetch a single row from a database, and the data is serialized as JSON [63]. Hence, low latency gives better performance for back-end frameworks.

### 5.3.2 Implementation of OPC UA Services

```
//Authentication service  
//Data acquisition  
//Discovery Service
```

### 5.3.3 Authentication of the Web-Based Software

//Firstly you should give an introduction about JWT

//Make shorter

A web-based software must have compliance with an authentication standard anyhow. One can mainly observe two kinds of authentication, which are certificate-based authentication and token-based authentication. Authorization is a higher-level representation so that one can implement a role-based authentication after authenticating a system. These roles can be broken into administrative and user roles. A system can assign different rights to these roles in order to provide a system's security or integrity. OPC UA Protocol introduces a certificate-based authentication before establishing a session. A Web-based software may perform security between its platform and end user. This called mainly API security and OPC UA Web-Based Software provides a JWT Authentication. With JWT Authentication, a token created by the back-end application of web-based software and is sent to the client side after a client performed an HTTP Request to an endpoint. A client or front-end application should send this token with every request that he wants to authorize while a process is executing. The carrier system called Authentication Bearer, which is carrying out a body of a request in HTTP Protocol. A user types username and a password to get access a token to fetch data from a web-based system. After initiated username-password pair check, JwtSecurityTokenHandler creates a handler of a token and SecurityTokenDescriptor launches a description of a token. The latter called SecurityTokenDescriptor defines expiration date and type of credentials such as Aes128, HmacSha384 or RsaSha256Signature. In our case, the practical implementation of a symmetric key has with Hmac Sha1 256 Bit Cipher.

JWT Authentication may work with Claim-Based Authentication that allows users to authenticate with claims. For instance, OAuth2 and OAuth Single-Sign-On Authentication Methods leverage Claim-Based Authentication by routing to an external layer of

software. An Issuer envelopes information such as Roles, User Domain or Account Name with a token by means of an Issuer Server. In order to authenticate multiple time with the same token, a system requires an Issue Server with straightforward information about a user to distinguish domain of application to be granted. In the general case, claims identify an expiration time of a token in the view of the fact that the system calculates the interval between the current value of time and token-validation time.

A compact way to provide security is to implement an authentication method within the low-level protocol area. Sessions have a variety of service set in OPC UA to create Session between a server and a client. Before calling a service set from a Server, OPC UA Client should create a session for the integrity of the communication. Firstly, a Session Service Set should provide an endpoint and a security model for constructing session management. A session can close a secure channel with timeouts to protect from an additional idle state of servers. Sessions should have encrypted natively before they send information into the upper level. For catering to protocol-level security, OPC UA Client employs a certificate-based authentication through an X509 Certificate to Certification Routing. This routing system prepares an authentication initiative to decrypt parameters of a certificate. At the same time, an OPC UA Client sends a secret message through Open Secure Channel initiated by a Session and message-certificate item pairs verified with an asymmetric signature.

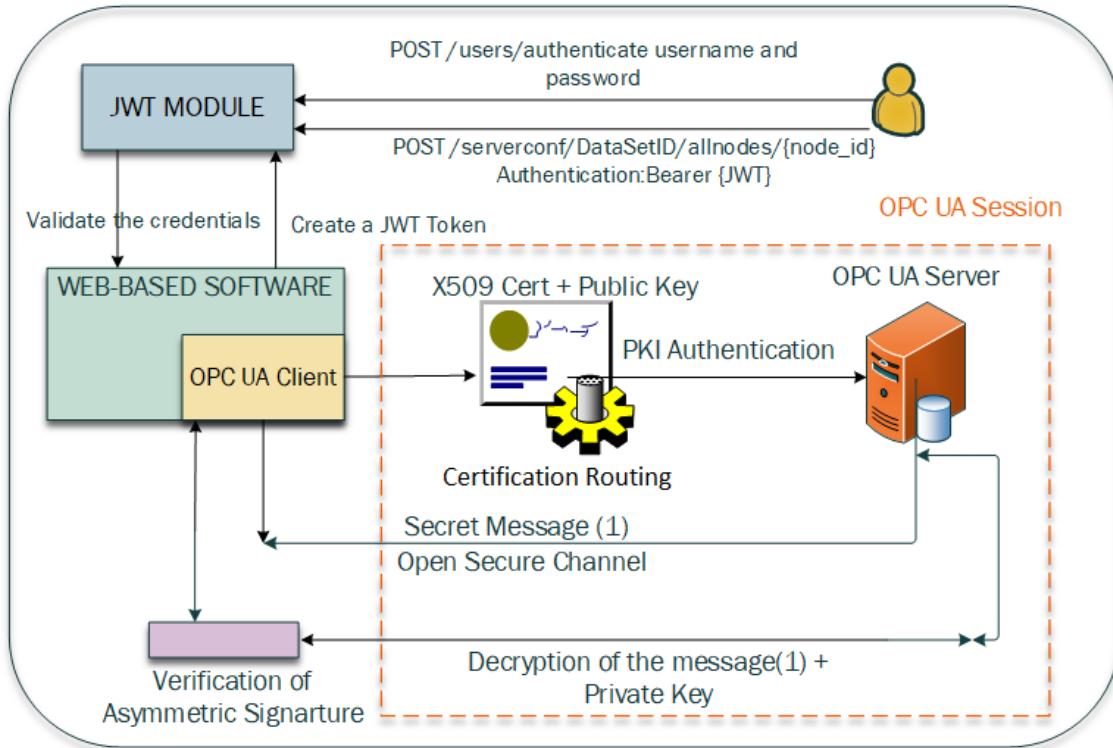


Figure 5.1: Authentication System in the Practical Implementation [64]

JWT Authentication is not the only method that a system can utilize through an authentication concept.

Kerberos and OAuth can be thought other versions for the authentication and authorization concept. In common, all three authentications employ issued tokens, but there are different from each other slightly. JWT is an unloading authentication, which means that an authentication system interrogates tokens in incoming requests.

Furthermore, a request that consists of JWT Token is not requiring extra configuration against endpoints. However, Kerberos Authentication needs a key distribution service and an authentication server. Initially, an incoming request sent to an Authentication Server to authenticate the request by user name and password pair. If a symmetric key used for authentication, the key distribution server should handle all requests to exchange keys instead of public-key infrastructure. This could lead to point of failure and security vulnerabilities. Another drawback about Kerberos, time limitation of a ticket does not allow time-to-live value such as JWT and OAuth2 and this time restriction must synchronize with clocks between servers.

Consequently, a Kerberos system expects more configurations than JWT and OAuth2 needs.

//Talk about Kerberos, OAuth authentication and benefits, drawbacks

//These authentication methods are described in the document called OPC UA Mappings

### 5.3.4 Data Manipulation and Navigation in OPC Unified Architecture

//Make shorter

For the part of Data Manipulation in OPC UA, the previous study has been used that has published by [6] [7] and Free OPCUA [65]. OPC UA utilizes tree-based hierarchical architecture to traverse among nodes with their references. Folders organize Address Space and they can abstract objects into Information Model. Complex type as predefined structures should comprise primitive type that can be reachable by OPC UA Client.

OPC UA Protocol defines its own data structures that break up into two main sections: Built-In and Structured Data Structure. When an OPC UA Client demands that is navigating through OPC UA Server, he should start from a root folder that consists of a root node. By sending a browse request to root note id that is equal for all standard OPC UA Server is id=85, OPC UA Client reach the terminal nodes of the tree structure in OPC UA Server. Generally, leaf nodes give standard information about folder, object and variables and continuous simulated data saved into the leaf nodes of OPC UA Server. OPC UA supports various data types up until top-level nodes in terms of object-oriented network design. There might be a misconception when sent a Read Request without parameter such as “namespace = 0” and “root node id = 85”. (Scroppi Et al. , 2017) reported that an OPC UA Client can send a read request without parameter so that the client will connect the object root node [7]. The practical implementation follows another way around like there is no hard-coded root node and namespace pairs for lucidity. An aspect of the web-based software, each user can send separate requests by creating a new session.

Navigation between nodes should consist of attributes and references as mandatory. Principally, a node attribute comprises the Browse Name and Node Id. “BrowseName” and “Guid” parameters as defined in OPC UA Protocol show initial names of nodes. Browse Names are matched onto Values and Datatypes. Browse Name and Display

Name similar to each other except that Browse Name represents itself with a namespace index. Practical implementation exhibits a node id – namespace pairs, browse name, type of data and type of reference. However, an aggregation server can be created as a cumulative address space. All connected servers to the aggregation server create their own address space in order to do so. In this case, the aggregation server defines multiple root nodes with namespace and a GUID. The practical application can be extended to show multiple roots, but the scope does not cover this point. Root Object has three items, which are Objects, Types, and Views. Views is a restricted address space created by an OPC UA Server. Restricted spaces have different definitions for Views that limits Nodes and References. Views are more useful when used a cumulative address space in opposition to a single address space because multiple address space should discriminate more dynamic and static data from multiple OPC UA Servers.

Serialization idea for reading and writing requests have been taken from the studies [7] [6]. The idea behind of serialization is converting OPC UA Server built-in types into JSON Schemas or Values. By way of JSON format, a web-based service can use the information through HTTP Request Payload to communicate between front-end and back-end architectures. Even though the features of built-in data such as description, binary schema, field type etc. saved as an XML schema in OPC UA Protocol, the XML format is not suitable for neither OPC UA Web-based software communication among modules nor a semantic question answering. By this means, an overhead of conversion of syntactic XML is not a problem while developing a web-based software or a semantic question answering. The approach comprises the Structured Data Type and Built-In Data Type which is converting into a JSON Format through serialization to send a proper response from OPC UA Servers [7] [34]. To navigate between Structure Types used an XPath navigation includes over 200 built-in functions for string values, numeric values, Booleans and node manipulations [66]. Most built-in types are encoded in XML Schema of OPC UA Standard Definition. A Client holds application configurations, data types of nodes, and security information with certificates as encoded in XML Schema. Due to being a structured data type, information parsing are relatively easy with labels within an XML Schema.

As a result, our findings are that XML Schema can handle the internal operation of OPC UA such as a definition of Node Types or extracting data types and JSON Serialization is a more valuable step to interoperate with web applications. Our application of generalization can convert XML Schema into RDF/XML through XLST processor. At transport

level, JSON Encoded messages exchange over an HTTP connection with a specific “Content-Type” and “Content-Length”. Another finding is about that XML Schema can define encoded Messages for SOA based applications. Bindings and Port Types for SOA Based applications have already defined within XML Encoding. Moreover, an HTTP Request can envelop a predefined XML Schema files such as Data Types within a body section.

```
[HttpGet("/api/serverconf/DataSetID/subscribeNodes/monitor_id) Authentication  
Bearer {JWT}]
```

Listing 5.1: HTTP Get Request for Monitoring Node (Should be posted)

This study handles a subscription request with a minimum sampling time interval of monitoring node id to register either a variable, an attribute, a node or an event. The Web-based software does not specify any minimum sampling time interval. In the practical implementation, one can prepare a packaged notification message with required monitored node id. The limitation of the monitored node is not all OPC UA Servers provide monitorable structure for variables or events. This restricts to follow all changes for manufacturing device and the only solution could be redesigning OPC UA Server in order to subscript changes within a particular time interval. Subscription connects to an existed session to prevent creating a redundant number of sessions. A lived session can be controlled from a common pool that has all session's identification numbers with their generic configuration.

After subscribing a request, one can fill up the subscription with a monitored node id. At this stage, the system should assign a sampling interval rate. The rate implements a cyclic rate that the server can sample data from real items. Sampling rate selection could be problematic in the implementation. A user or an internal application can make the selection. For instance, monitored part of the application select 1000 ms sampling interval, which is the most common interval rate selected by OPC UA Servers. If the 1000 ms has been selected although a server does not support the rate, the server assigns the most applicable rate in order to apply a sampling rate. The selection process may be different server by server. Regardless of a sampling rate below than a particular value or upper than that, server creates a subscription to insert a monitored node into the subscription. User can take an exception from protocol stack regarding mismatching interval rate, either way a subscription is produced. Another finding is that the underlying structure of

subscription mechanism of OPC UA Servers is not thread safe. That means a client implementation should be aware while multiple monitoring nodes could create a delay for results. Consequently,

//Why Monitoring Nodes

//How to implement Nodes

//What exactly it is

//What benefits we can get

//What are the drawbacks

### 5.3.5 Implementation of the Semantic Question Answering

Semantic Question Answering System is a detached module that conforms with Model-View-Controller Pattern. In a similar manner of OPC UA Web-Service, a platform can send a rest request independently unless they have a proper token created by the service. A Test Page for Question Answering System works with the link under “<http://localhost:5000>”. Semantic Question Answering System can take HTTP Request from OPC UA Web Service so as to have an integration through modules. Python Flask handles with all request coming from users with daemon threads. With respect to daemon threads, the system presents a multi-thread environment without paying attention to the termination of threads. For instance, when two of HTTP Request into both module OPC UA Web Service and Semantic Question Answering, the system without daemon threads should take care of termination manually. This causes a bottleneck for a system known as multi-thread resource termination. Daemon threads make respectively stop all threads after exiting with their resource from HTTP Requests. As shown in Figure 1.1, Semantic Question Answering has multiple steps to achieve a result from its resources such as stop word removal, tokenization, lemmatization and stemming, WordNet analysis, question classification. Chapter 5.3 explains the theoretical treatise of every step and this chapter will introduce the practical implementations with different libraries. Many applications of question answering use the answer scoring method before taking answer with SPARQL queries. Mainly, natural understanding part of this thesis used a bunch of libraries such as Spacy, Textblob, NLTK, Stanford CoreNLP with annotators and Restful services. NLTK mostly used for tokenization part in order to handle inputs

without an overload of library functions. Principally, tokenization and stop word removal is not memory overhead operation because these two steps only need a list of English lexicon to identify words.

We have used partial parsing and parsing based on machine learning through natural language processing libraries altogether. Firstly, the semantic question answering applies a shallow parser to identify an essential sequence in order to combine with a subject-predicate-object pattern. If such a pattern found in a given natural query, the question answering should chop the unnecessary items such as adjectives and adverbs except for nouns and verbs.

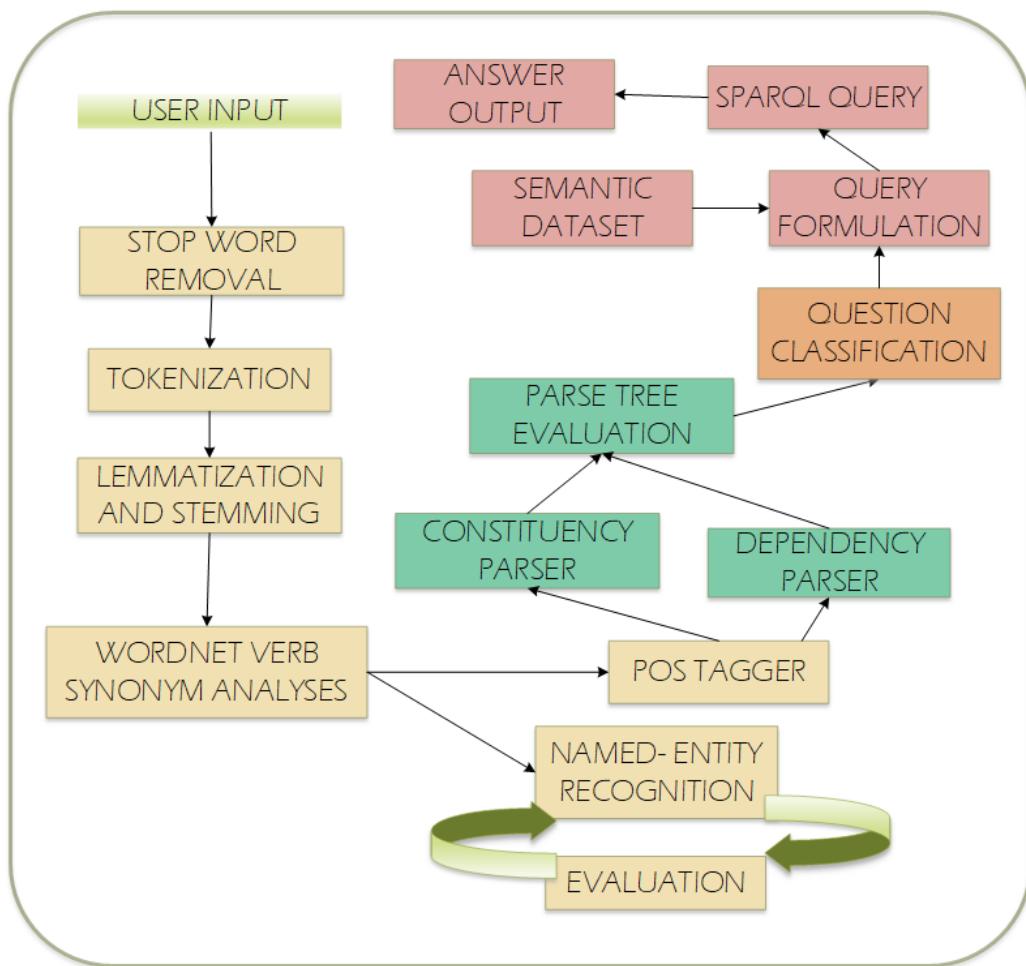


Figure 5.2: The Algorithm of the Semantic Question Answering

Every query formulation phase should follow the flowchart as shown in Figure 5-3. An input should clean unnecessary characters with stop word removal and tokenization functions. All of the elements illustrated in Figure 5-3 has represented in different classes in an application. The lemmatization step clears the prefixes to compare the synonym of the word. Unlike an open-domain question answering, we could not implement a rule-based approach. For instance, a template-based approach gives precise answers with a predefined set of a statement such as <?noun, property, ?object> [21].

Moreover, the question classification phase affects answer ranking. If a question answering system gets a large scale of data, the system can score answers of questions to indicate in a better way. These two aforementioned approach is not suitable for restricted-domain question answering according to our experiment. Data scarcity does not only affect implementing a machine-learning algorithm but also makes a question answering based on information retrieval harder. That means a semantic question answering that exploits restricted source should focus on an in-depth parsing approach. After implementing the semantic question answering, a question classification used for eliminating answer types rather than scoring the answers.

The semantic question answering employed a limited linked data represented as Turtle RDF for static queries. The statements i.e. “What does linkedfactory contain” or “Please give me all of its members” were asked to the question answering. One of our findings is that an upper or lower case of question can produce different results from constituency parser unless we turned into a lower case of them.

**Algorithm 1** Query Formulation

---

```

1: function QUERY FORMULATION(a, b)                                ▷ Explain here
2:   query  $\leftarrow$  QueryWithPrefixes
3:   r  $\leftarrow$  constituent.parse.tree
4:   indirectdependency  $\leftarrow$  dependency.parse.tree
5:   while nodes  $\neq$  leafs.terminal do          ▷ Until leaf nodes(Terminals)
6:     verbs  $\leftarrow$  PARSER(nodes)
7:     nouns  $\leftarrow$  PARSER(nodes)
8:     similarityflag  $\leftarrow$  WORDLATENANALYSIS(verbs)
9:     if StaticInformation is True then
10:      indirectdependencyFlag  $\leftarrow$  DEPENDENCYPARSER(nodes)
11:      if similarityflag and IndirectDependency is true then
12:        object  $\leftarrow$  nouns
13:        predicate  $\leftarrow$  verbs
14:        query  $+=$  object + predicate + ?subject
15:      else
16:        subject  $\leftarrow$  nouns
17:        predicate  $\leftarrow$  verbs
18:        query  $+=$  ?object + predicate + subject
19:      if DynamicInformation is True then
20:        predicate  $\leftarrow$  PARSER(nodes)
21:        object  $\leftarrow$  PARSER(nodes)
22:        similarityflag  $\leftarrow$  SIMILARITLEVENSHEIN(input)
23:        query  $+=$  object + predicate + ?subject
24:   return query                                ▷ The last query has been constructed

```

---

Figure 5.3: Query Formulation Algorithm

The algorithm as shown in Figure 6-5 is evaluating the queries within two main sections. While static queries are sent against local linked data endpoint, dynamic queries need an API to get through federated services. A human operator must do this separation when he or she asked. Numerical keywords such as “value”, “average”, “minimum” or “maximum” are key points of a semantical separation between static queries or dynamic queries.

//Heuristic based statistical methods

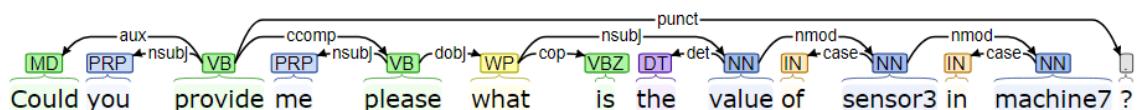


Figure 5.4: Dependency parser

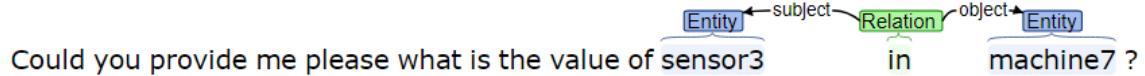


Figure 5.5: Named-entity recognition

//Give the reference for the test dataset

| Parameters   | Precision | F1     | Recall |
|--|-----------|--------|--------|
| <b>Newton-cg</b>                                   | %95.55    | %95.56 | %95.57 |
| <b>Linear SVC</b>                                  | %92.75    | %92.76 | %92.77 |
| <b>Limited<br/>BFGS</b>                            | %94.21    | %94.22 | %94.23 |
| <b>Logistic Re-<br/>gression CV</b>                | %95.63    | %95.63 | %95.64 |
| <b>Linear SVC<br/>for Li&amp;Roth<br/>Taxonomy</b> | %65       | %45.5  | %35    |

Listing 5.2: The Question Classification of Li&Roth and Wh-Question Taxonomy

## 5.4 The Realization of Architectural Design in the Assistance Web-Based Software

//Once API Tasarımı

//Monolithic ve Microservice design

//Natural Language processing implementation

At this chapter, OPC UA Web and Integrated Semantic Question Answering Architectures are giving to examine structure that comprises software elements and relations

among them. JSON Web Token (JWT) is an open standard (RFC 7519) that defines a compact way to transmit information among generated JSON Objects. Before all requests taking from web users, a load balancer can balance the volume of requests and split up the resource of the system regarding queries. The practical work of thesis provides a load balancer to give an ability to assigning multiple resources into equal space of cores regardless of the domain and scope of the web-based software. The architecture resembles a monolithic application that contains all modules connected to one single load-balanced endpoint, unlike Microservices. This thesis uses the approach of API gateway which improves the usability of libraries comprises a more complex structure with a simple API entry point.

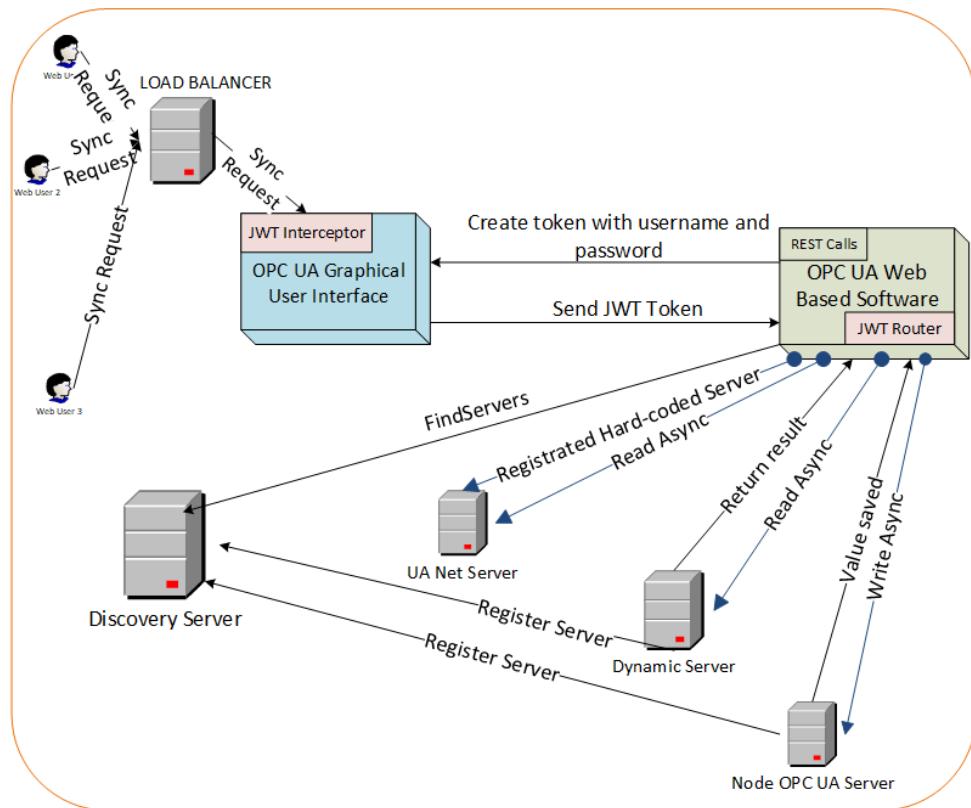


Figure 5.6: General Architecture of OPC UA Web Application //Add Question Answering

As shown in Figure 1.1, the architecture of this thesis comprises an authentication mechanism, RESTful service handler. OPC UA Protocol handler and Semantic Question Answering. OPC UA web-based software can support every type of data structure which is used in communication stack defined by an XSD document.

ASP.NET Core commences the API entry point with “API” keyword. All regardless sort of requests is sent with “api”.

```
[HttpGet("api/authenticate/")]
    Body of Request {username, password}]
```

Listing 5.3: HTTP Get Request for token-based authentication

As show Listing 6-3, the system has a get request for authentication with user name and password. The practical implementation incorporates a hard-coded username and password, but ASP.Net Core can implement temporary username-password pairs with an in-memory database. Authentication HTTP Request is an initial point to get access from API Gateway. A sample request of authentication as shown Listing 6-3. After matching username-password pair, a JWT token is being created to direct other requests into a controller. A developer can define the JWT Token for a short duration unless the time to live value (TTL) of server expires. Other routings of ASP.NET Core are protected with ASP.Net Core Headers such as [Authenticate] and [Allow Anonymous]. A malicious request without a proper JWT token cannot be sent that way. After an HTTP Request authenticated with a token, the request bypass the Header named [Authenticate] by letting the request anonymously.

An HTTP GET request for node information has been reformatted again from the work of [Scroppi Et al., 2017] [7]. In this work, the expiration time of a JWT token restricted with minutes; however, when the practical implementation has been tested under heavy load testing, a point of failure could create a bottleneck if JWT token authentication would have expired within minutes. So expiration date of the JWT Authentication has been changed in the practical implementation. In particular, a node-id is a mandatory field in the request as below in Listing 6-2.

```
[HttpGet("api/serverconf/DataSetID/allnodes/{node_id}")]
    Authentication Bearer
    {JWT}]
```

Listing 5.4: Http Get Request [7] [6]

To connect OPC UA Servers, a client can use

//Talk about the way to the connection of OPC UA

//Websockets, TCP, HTTPS

//Websocket needs a high rate of polling to stay the connection up rather than having a repetitive connection setup for each request. Good match for real-time

//Mixed connection with HTTP and HTTPS are vulnerable to attack. HTTPS never be cached. When an HTTPS used between browser and server, proxies cannot see the shared cache, which can be dangerous for the communication environment. Encryption has overhead for both server and client. Certification creation overhead between client and server. However, OPC UA CA sharing solves this issue

//TCP connection provides a basic level connection without overhead.

The web-based software is capable of writing a value into a writable object. This is a limited feature against servers because most of the OPC UA Servers have some restrictions in order to protect from vulnerable attack. However, simulated data in any object can allow writing in the structure for testing purpose.

```
[HttpPost("api/serverconf/DataSetID/allnodes/{node_id}) {value:"message"}  
Authentication Bearer {JWT}]
```

Listing 5.5: Http Post Request [7] [6]

```
[HttpGet("/integratedstaticmessage/{question} Authentication Bearer {JWT}]
```

Listing 5.6: Question Answering Static Message HTTP

```
[HttpGet("/integrateddynamicmessage/{question} Authentication Bearer {JWT}]
```

Listing 5.7: Question Answering Dynamic Message HTTP

//Talk about load balancing with NGINX and RabbitMQ non-blocking IO queue.

## 5 PRACTICAL IMPLEMENTATION

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HTTP Request can be repetitive and consecutive methods triggered by a user. Taking into consideration an increasing amount of data in industrial networks on a daily basis, an architecture should comply with the load balancing and non-blocking input-output queues.

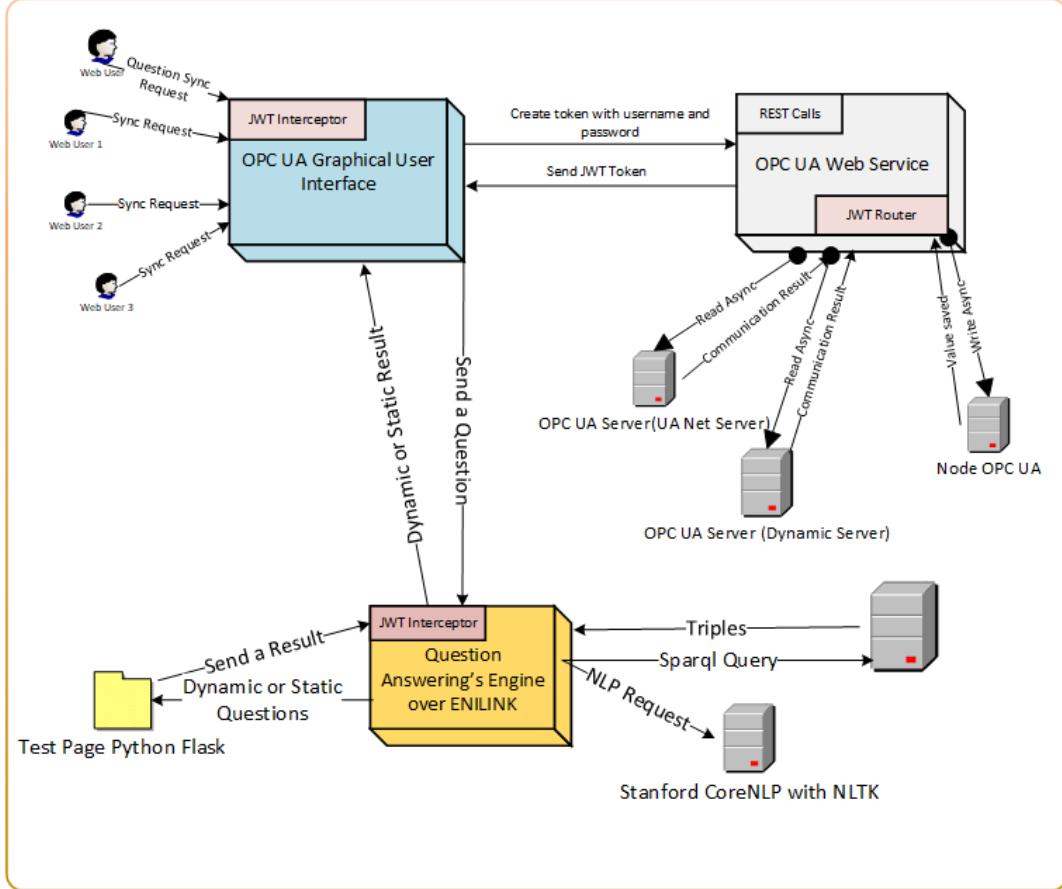


Figure 5.7: RESTful Semantic Question Answering System

## 6 Experimental Results

In Chapter 7, we will explain the test parameters for the general suite of Web-based software. We evaluate the OPC UA Client feature of the web-based software with some parameters, e.g. viability of unit testing, mock testing, and load testing. We separately evaluated the Semantic Question Answering with the precision of answers and usability of the question answering. Our main theoretical motivation is to provide an assessment of performance for the general system. OPC UA Client is hard to test with mock testing because creation a session at the protocol level for each request could freeze the system. A load testing would use for testing main functions of the web-based software, e.g. opening a session, sending a request, serialization of objects, and closing a session. A timeout value of testing tool and OPC UA Client should overlap, otherwise, results of performance or load testing can give us wrong results in terms of failed requests. A question answering needs the Precision, Recall and F1-Score for evaluation. The list of meanings has been listed in Chapter 7.2 Materials and Methods. RESTful API requests are equally important for testing as performance testing. Randomly selected requests with JWT authentication and their results are shown in Listing 7-1. In the evaluation phase chiefly two questions I will be asked for

- 1) What is the accuracy of the question answering according to combined questions?
- 2) What is the performance and measure of functionality of the assistance web-based application?

### 6.1 Test Methods and Environment

Before testing the environment, we will explain the data sets and key points of testing phase. We have focused two semi-structured data set that has been identified with IRI parameters. The first data set is relevant to eniLINK that comprises key-value mapped streamed data and eniLINK hierarchy data. The hierarchy data contains totally 35 triples about hierarchical structure of the Fraunhofer IWU Smart Factory. The latter

//Talk about serialization results

## 6 EXPERIMENTAL RESULTS

---

OPC UA Web-Based software is an all-in-one application that combines OPC UA Client over Web, generator tool for OPC UA Servers and a semantic question answering. We will evaluate the web-based software in terms of latency and load testing. As for the question answering, we have parameters to assess system with precision, accuracy, and recall. Question Classification method also assessed with machine learning methods and given results as presented in Chapter 7.3. Unit testing applicability of the system is a test parameter for a web-based software. Given RESTful, calls in Chapter 6.3 were tested and results are shown in a table.

ASP.NET Core and Flask Backend Frameworks have unit testing to test important features of an application. Due to the dependency injection and routing mechanism of ASP.NET Core, we have tested through mock testing by creating a tampered controller with sample options. Such options added a different JWT authentication for test purposes. The aspect of the Semantic Question Answering, we have test cases RESTful API, Asynchronous and Synchronous Communications, and natural language processing toolkit over language inputs. We have created a session-based evaluation to test the OPC UA Client and OPC UA Web-based software together. In these tests, we have a time parameter that shows the duration of the test to run in seconds and a session parameter that indicates the number of sessions to run simultaneously. By increasing the number of threads slowly, we test how well the system reacted to parallel sessions. The main intentions are to show the degree of efficiency of the system under peak loading and burst to load and indicate how the architectural changes like adding load balancer affect the results. In a single session, the OPC UA Web Based Software Front-End will send a session that contains a JWT deserialization, a read request with node id, JSON deserialization, and an HTTP Response. Whether considering that OPC UA Client has a Session Instance separately from the web-based software, the request timeout of testing should be equal with OPC UA Default Session Timeout.

Firstly, ---- talk about first REST testing in the result page.

Secondly, we determined a set of conditions that we will test whether the system may give us a satisfying result. Within 60 seconds, we send multiple requests to different OPC UA Servers at second within sessions simultaneously 20, 25, 30, 35, 40, 45, 50, and 200 respectively. Then within 30 seconds, we send multiple requests to different OPC UA Servers at second within sessions simultaneously in the same order of session numbers. In the section titled Results 7.3, the graphs depict the number of requests and average request time. This combo chart comprises a line chart and a bar chart so that the line

chart depicts the total amount of request time and the bar chart illustrates the number of requests.

//To evaluate the Semantic Question Answering, we should also assess a web server //because the nature of the question answering simply is a web server. Multitasking is //one of the important testing parameters while assessing.

As for the Semantic Question Answering System, we calculate system performance with precision, recall and F1 Score values. Moreover, we analysed the research of [Ozgur Yilmazel et. al.] [24] introduced the parameters of a restricted question answering might have “answer return rate”, “querying style”, “user interaction”, “coverage”, “size”, “upto-dateness” and “formulation assistance”. Querying style can consist of keyword-based and sentence-based queries. Answer return rate measures how long an answer takes time after submitting a query by a user [24]. We can define the metrics of “coverage” with the research-domain that we have elaborated. “Size” could be measured with generated data, static data, and continuous-data produced by the eniLINK system.

**Precision** = True positives / (True positives + False Positives)

**Recall** = True positives / (True positives + False Negatives)

**F1-Score** =  $2 \times \text{Precision} \times \text{Recall} / (\text{Precision} + \text{Recall})$

**Accuracy of the Model** =  $(\text{True Positive} + \text{True Negative}) / (\text{True Positive} + \text{False Negative} + \text{False Positive} + \text{True Negative})$

//**Recall** = Sensitivity

//**Precision** = Positive predicted value

Moreover, the performance of question classification affect the results of the question answering system. In the practical implementation, the semantic question answering expose Li&Roth taxonomy classification and “Wh” typed question classification. The goal of evaluation for question answering to show the percentage of elimination by eliminating unnecessary answer selection.

Question Classification is the final step before implementing a query formulation. We have grouped Li & Roth Taxonomy and Wh-Question Taxonomy, which are essential categorization, used in question classification. Wh-Typed Question comprises of “wh-typed”, “who”, “why”, “affirmation” and “unknown” types of questions. “Who” and

## 6 EXPERIMENTAL RESULTS

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“why” question is the type of “wh-typed question” but it is irrelevant for the semantic question answering. Li & Roth taxonomy are divided into 6 coarse-grained categories such as “Abbreviation”, “Entity”, “Description”, “Human”, “Location”, and “Numeric”. Dynamic Questions utilizes to classify with Li & Roth taxonomy and static questions expose to classify “Wh-Question Taxonomy” in order to identify unrelated questions.

//Talk about dataset size

### 6.2 Results

We defined RESTful HTTP calls for OPC UA Client Web-based Backend and the Semantic Question Answering Backend. RESTful calls should allow requests after authenticating with JWT tokens. As shown in Listing 7-1, every request followed the basic principle. Mock testing and unit testing implemented to the application and results are as depicted in Listing ..

Tests were selected randomly that can represent functional tests of communication for the web-based software.

//how the data was gathered and what it is intended to represent

//what the gathered data looks like

//how it should be interpreted.

| HTTP Call                      | Test                          | Expected Output                 | Result |
|--------------------------------|-------------------------------|---------------------------------|--------|
| [HttpGet("api/authenticate/")] | Send the request without JWT. | HTTP Not Found<br>404. Action S | OK     |

|   |                                     |  |    |
|---|-------------------------------------|--|----|
| <code>[HttpGet("api/serverconf/DataSetID/allnodes/{node_id}")]</code>                     | Send the request without JWT.       | OK 200. Reroute to the login page        | OK |
| <code>[HttpPost("api/serverconf/DataSetID/allnodes/{node_id}){value:"message"} ) ]</code> | Send multiple consecutive request   | OK 200. HTTP Response with JSON          | OK |
| <code>[HttpGet("/integratedstaticmessage/{question}")]</code>                             | Send the request without JWT        | 404 Not Found. Reroute to the login page | OK |
| <code>[HttpGet("/api/serverconf/DataSetID/subscribeNodes/monitor_id" )]</code>            | Send the request with the wrong JWT | 404 Not Found. Reroute to the login page | OK |
| <code>[HttpGet("/integrateddynamicmessage/{question}")]</code>                            | Send a PUT Request with right JWT:  | 405 Method Not allowed.                  | OK |

Listing 6.1:

Results were grouped with the duration of the test that we have done. For instance, a test application creates a variety number of sessions to test a single instance of a web-based software for 30 seconds. As shown in Figure 7-2, there are no failed requests under specific circumstances. These failed requests also depend on the type of OPC UA Server. Hence, we should take into consideration to use the same types of a server so that we can provide equal conditions. In our case, we tested the system with two different OPC UA Servers. Due to the scope of the testing phase, the type of servers is irrelevant in order to reach precise results. The total amount of requests are changeable because the server threads can respond back within unspecified delayed. As illustrated in Figure 7.2, maximum request time, minimum request time and average request time are increasing when we reached 50 and 200 sessions. Nevertheless, there are no failed requests even if the number of requests increased from 40 sessions to 200 sessions.

## 6 EXPERIMENTAL RESULTS

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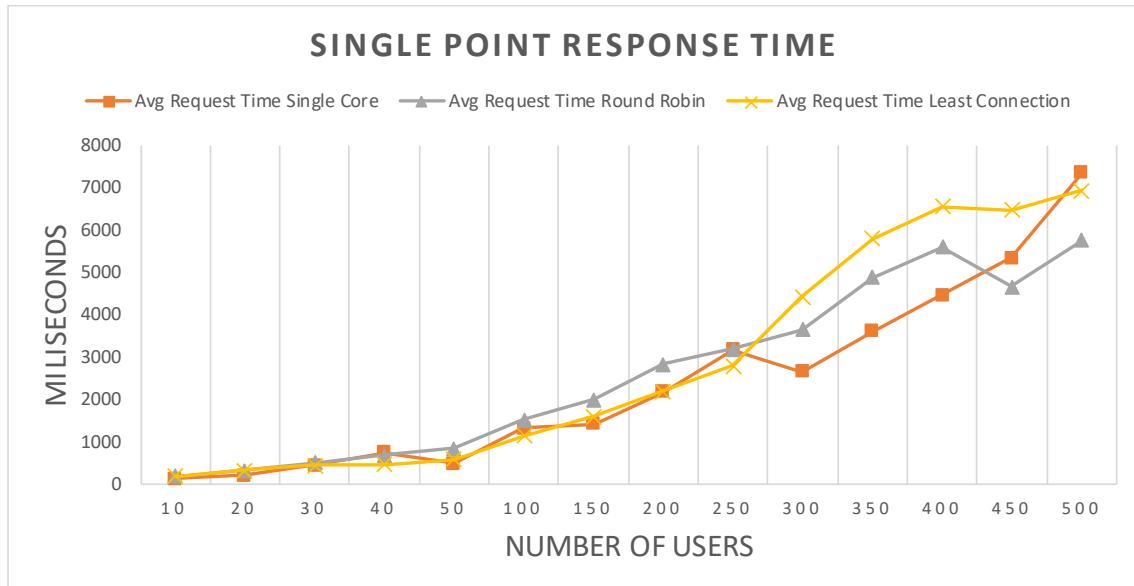


Figure 6.1: 30 second Single Point Response Time

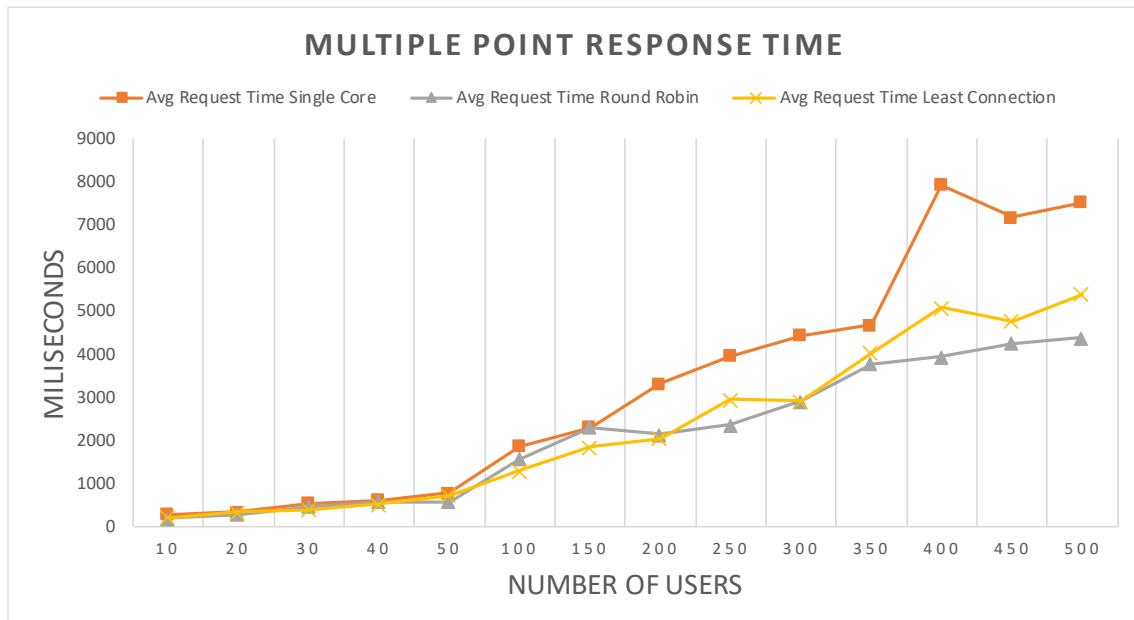


Figure 6.2: 30 second Multiple Point Response Time

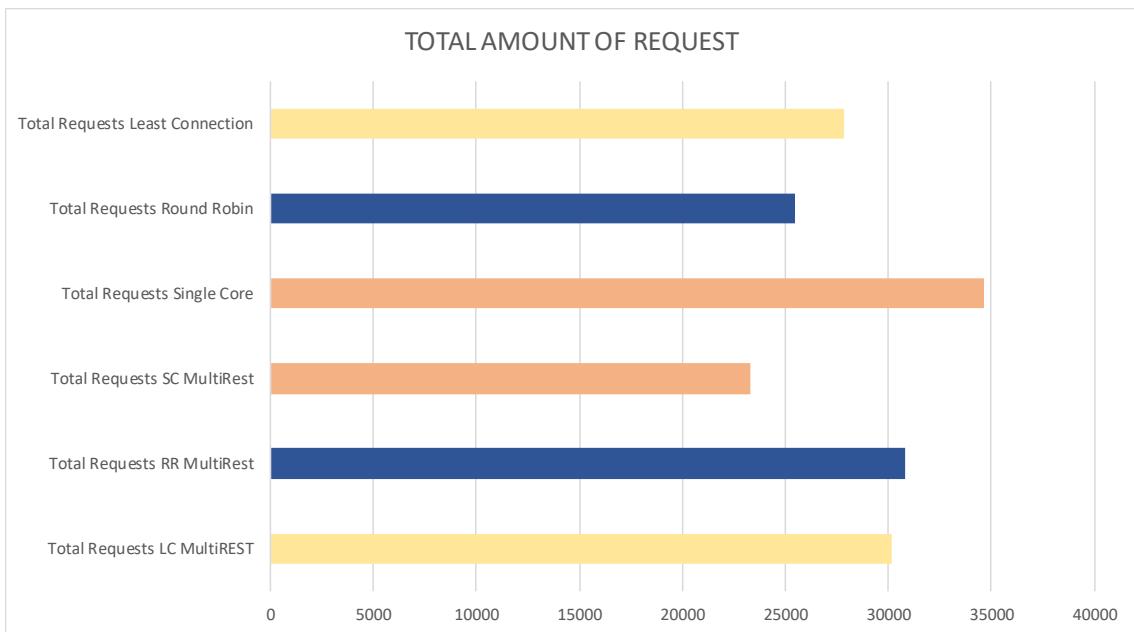


Figure 6.3: 30 seconds Total Amount of Requests

The number of total requests is similar to Figure 7-2, but maximum request time tends to decrease 40 sessions later. Average time and Max request time decreased dramatically with the round robin load balancing algorithm from 40 to 45 and 50 to 200. The Round robin and least connection load balancing reduces the amount of average time after 50 sessions. While the OPC-UA web-based software creates maximum throughput for round robin and non-load balanced application under the number of sessions 20, 35, and 50 respectively. Unexpectedly, the least connection within the 30s as shown in Figure 7-3 could not create the same amount of throughput as compared to Figure 7-2 and Figure 7-1. Under the round-robin algorithm, the system created the least amount of minimum number requests so that it reduced the average time of requests.

## 6 EXPERIMENTAL RESULTS

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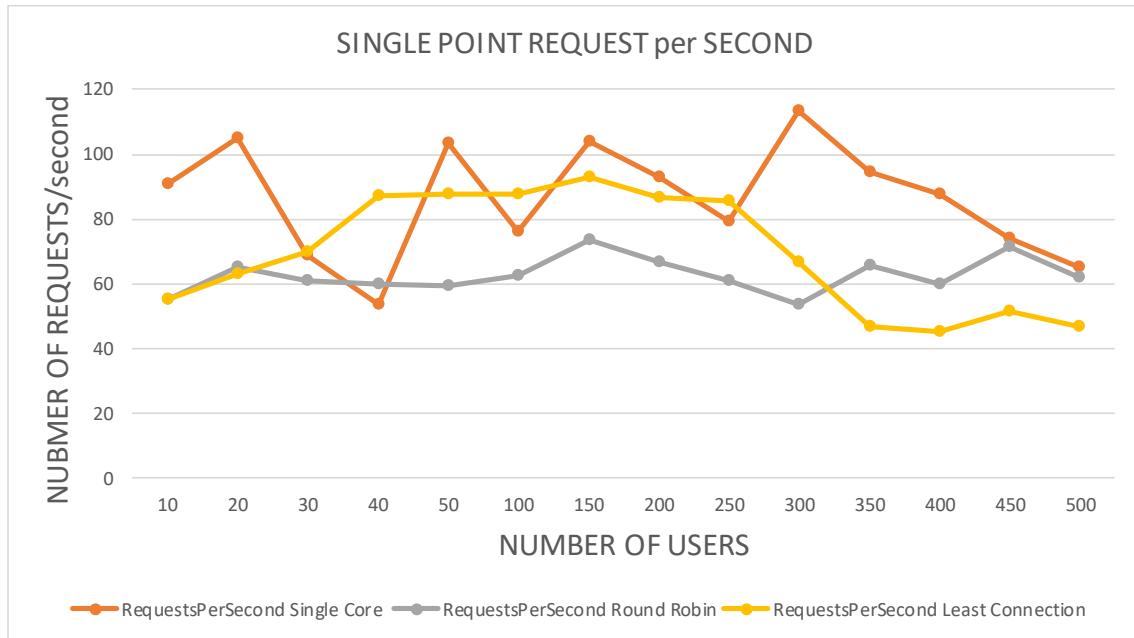


Figure 6.4: Single Point Request per Second

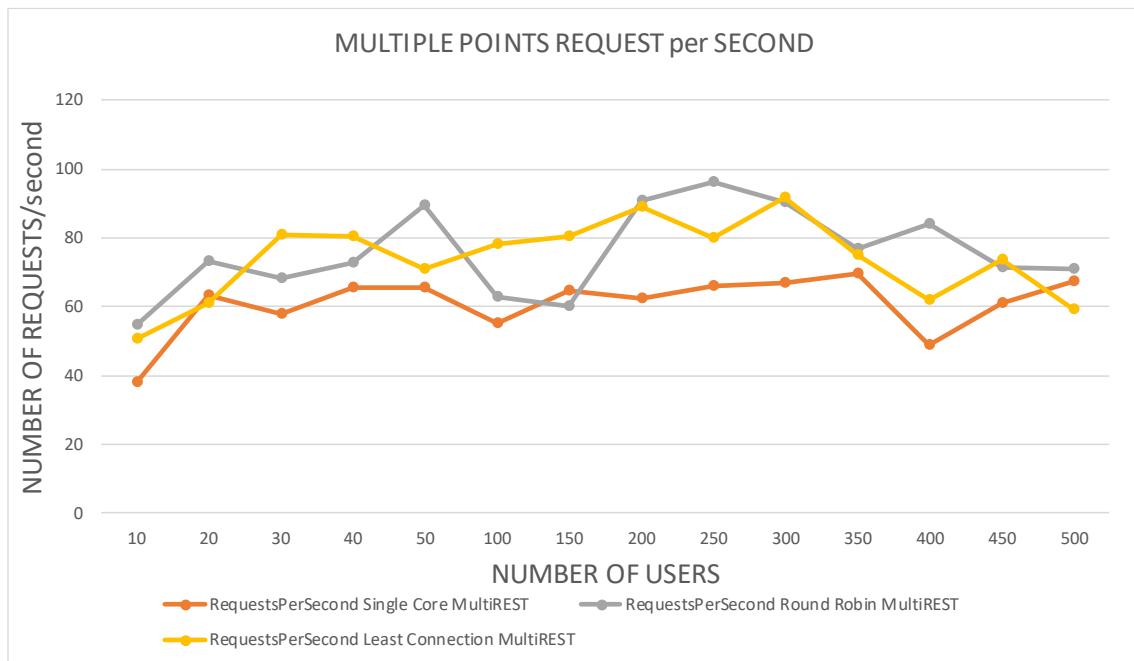


Figure 6.5: Multiple Points Request per Second

The tests during 60 second give different results aspect of request time and the number of requests.

In the semantic question application, we have a voice recognition that we use for natural queries by voice inputs. Voice-recognition is struggling to identify domain-specific words such as “fofab, gmx or glt”. The reason that generic voice recognition could not identify domain-specific keyword is named-entity recognition. We should train named-entity recognition with our domain-specific data in order to use voice recognition with the semantic question answering in an efficient way. However, a voice recognition alleviates inputs size and it is more efficient while we are typing nouns, verbs, question words or adverbs. An abbreviation solver and a spell checker could be a question assistance system. Abbreviation solver is a recognition task for general abbreviations such as “A.S.A.P. – As soon as possible” or “A.A.A – The Agricultural Adjustment Act” domain-specific task as well. Compound words such as “linkedfactory” and “heatmeter” must be trained domain-specific keywords by means of named-entity recognition, otherwise regex-based or character based might not give precise results more than train-based did. The practical application provides a spell checker without a guidance system.

| Evaluation Parameters               | Properties  |
|-------------------------------------|---|
| <b>Answer Return Rate</b>           | Generated Data from OPC UA – 39.88 second –<br>Consecutive Query of Generated Data 12.31 second<br>Static query from RDF file of eniLINK – 19.33 second<br>Dynamic Query – 17.48 second<br>Open-Domain Question Answering Query – 20.55 s |
| <b>Querying Style</b>               | Keyword-Based Search and Semantic Search  |
| <b>Coverage</b>                     | eniLINK data, linkedfactory streaming data  |
| <b>Size</b>                         | Static data relatively small size<br>Continuous data relatively large size  |
| <b>Up-to-dateness</b>               | No update statement provided by SPARQL  |
| <b>Query Formulation Assistance</b> | Voice Input Recognition, Spell Checker  |

## 6 EXPERIMENTAL RESULTS

---

Listing 6.2: Evaluation parameters of the Semantic Question Answering

| Question Answering | True Positive | False Negative | False Positive | Precision | Recall | F1     | The Accuracy of the Model |
|--------------------|---------------|----------------|----------------|-----------|--------|--------|---------------------------|
| Total Questions    | 34            | 13             | 3              | %94.44    | %72.34 | %81.92 | %68                       |

Listing 6.3: Total answers from Semantic Question Answering

As listed in Listing 7-1, answer return rate of the semantic question answering is close to open domain question answering. The environment of the practical part should load the vector and dependency dataset to avoid repetitive loading. Hence, consecutive queries are faster than the first query sent by experts or users. A user can search with keywords or semantic (sentence or question) words the results within the question-answering module. Data size is relatively changeable between a static search and a dynamic search. Dynamic search exploits continuous data generated by a time series and a key-value database. Sending a query to a SPARQL endpoint takes time due to the processing time of the SPARQL engine. Nevertheless, the dynamic search can respond within 30 minutes, which is a similar time value as compared to the static search. The semantic question answering does not allow updating to a triple because changes of triples in Turtle Source can create a vulnerability. The data source covers statically linked data generated by the Dynamic Server or eniLINK and dynamically linked data by KVIN Service. Last but not least, query assistance has been provided by the semantic question system to improve the search quality and ease of use.

As shown in Listing 7-2, a question classification can find a classification subset of questions with a machine learning method. As previously described, this thesis considered Support Vector Machine and Logistic Regression. The semantic question answering does not use a multi-layer perceptron, which is one of the deep learning methods, thereby taking a long time to train data. Logistic Cross-Validated Regression gives the better result under a 1559-lined labeled dataset. The Linear SVC has been used to train Li&Roth taxonomy, but unexpectedly the accuracy, precision and F1 Score values gave a lower

performance. On the other hand, the Linear SVC created a result over %90 for the dataset of Wh-Question Taxonomy.

Listing 7-3 shows us the answer rate of the semantic question answering. In Chapter 7.2, we have explained the parameters of Precision, Recall, F1 Score, and Accuracy of the Model. All of the parameters are above than %60 percent. We can

Listing 7-6 takes into consideration to answer to Factoid Question, Keyword Question, Indicative Question, Boolean Question.

//Start to write the conclusion part

//Another result is about imbalanced data sets. Compare the sets of accuracy

## 7 Discussion

- Comments on your results
- Explains what your result mean
- Interprets your results in a wider context; indicates which results were expected or unexpected
- Provides explanations for unexpected results.

//Architectural decisions could be important for the overall application.

//Semantic question answering still hard to generalize because of keywords.

//Integration thought was hard. After clearly defining architecture as microservices, components can be detached easily.

### 7.1 Introduction

//Compare monolithic and microservice design issues.

Like all natural language processing applications suffer from word-sense disambiguity, our application could fall into a failed situation after initiating some queries.

In order to create the semantic question answering, we have used regex-methods, POS Tagger, Parsing,

Type of domain plays a very important role to decide natural language processing algorithms where an algorithm will be used. The semantic question answering is a part of restricted domain question answering that takes linked data defined as triples. Details of an Experimental Development

//Talk about the importance of deployment while using a library for the natural language understanding.

Based on the extensive support of SDK aspect of OPC UA, Frontend and Backend of OPC UA Web Based Software can be developed in any programming language. Moreover it should be evaluated in terms of End to End Productivity, Interoperability, Versionability, Testability and Mockability, Learnability. In this chapter OPC UA SDK (Software Development Kit) will be discussed. Both open source and commercial, there are extensive support to develop OPC UA Stack and its applications. Not only SDK will be evaluated aspect of essential properties related to SDK, and also will be assessed extensibility of SDK regarding the feature itself.

## 7.2 Assessment of Research Questions and Hypotheses

RQ 5) Are the components of OPC Unified Architecture are good enough to make a factory-wide architecture concerning industrial communication and question answering?

RQ 6) What would be the optimal web architecture aspect of robustness, security, ease of use and high performance to generalize the operator assistant web-based application in a smart factory?

RQ 7) Can a semantic question answering utilize heterogeneous linked data source (e.g., OPC UA Information Model, streaming data, static data, and plain-text documents) in the domain of smart factory?

RQ 8) Can we scale our approach to other smart factories or plants?

### Hypotheses

H 4) The modules of proposed architecture will not affect each other in the context of performance and functionality.

H 5) The proposed system will provide precise and correct results.

H 6) Existing algorithms and design principles in the previous researches can be applied to the operator assistant web-based software.

In this chapter, we will answer the questions that have defined in Section 1.3. We will show a discussion by keeping a critical mind to do so. RQ 5 has shown an interest of architectural design of a factory-wide application. OPC Unified have many parts that could be less relevant to the goal of this thesis. Nevertheless, subscription, discovery, information and address model are suitable enough to realize as a web-based software that could be used by human operators. The problematic part is emerging while bringing into OPC UA stateful communication and REST stateless communication. Communication timeout of server can block the stateless requests in the high load created by multiple users. The evaluation shown us the issue can be surmountable assigning high timeouts rate. At that time, throughput of general request can decrease and due time can dramatically increase.

In this chapter, we will answer the questions that we have defined in Chapter 1.3. OPC UA Web-Based Software has targeted multiple roles in accordance with data acquisition from OPC UA Servers, creation of the linked data, and a question answering system. The main goal was to create a combined a Human Machine Interaction tool that could be used in a smart factory. Moreover, we point out general problems so that other smart factories can develop their own solutions. First, a technical user or a web user does not need to know detailed system architecture. However, the semantic question answering needs specific keywords that technical personals only knows. This issue is not a bad evidence for a question answering system because a restricted-question answering system can face such issues that we have examined in Chapter 2.2. A drawback of the web-based software can suffer performance problem if the system is implemented large-scale network because of architectural requirements. For instance, the division between smart factories demand different volume of performance while using the web-based software. Our finding is to identify most loaded parts in the web-based software and take countermeasure with a load balancer. According the experimental development phase shows us that a monolithic and a loose-coupled architecture can meet the requirements at a basic level. In order

to implement a system that is more complex with gateway integrated into micro-services can meet requirement of remote smart factories. Another drawback is a latency problem that caused by consecutive queries. We have experimented load balancing between web user and front-end application and among back end application with non-blocking input/output queue. As for the question of “Which technologies should I use?”, a software developer has variety of opportunities that described in Chapter 6. While backend frameworks need performance of serialization of JSON and XML data and low latency, frontend framework expect to handle dynamic user interface and data binding and asynchronous features. Moreover, pros and cons of technologies have been listed in Chapter 6 in a detailed way. So we can answer the question “Why these technologies have been used?”. Serialization of the OPC UA Address Space has been examined in Chapter 4.1.4 and 4.1.5. As previously mentioned, we should entirely take into consideration continuous data and static data. KVIN Service handle continuous data by mapping key-value pair with LevelDB. After testing with the question answering, natural queries can give result with SPARQL query. On the other hand, we reached the goal of how we can send a query to OPC UA Servers by means of using linked data. The Main reasons that we constructed the semantic question answering are allowing implementing an information extraction system, reducing errors because of SPARQL queries, and exemplifying a restricted-question answering aspect of smart factories. (Evaluation of Question Answering)

Chapter 7.1 detailed parameters of the evaluation

## **8 Conclusion**

### **8.1 Summary**

OPC UA Web-based software is an essential task that meets the general requirements of the OPC UA Protocol. Due to the enormous size of data produced by OPC UA protocol or production machines, human operators need a guidance system that alleviates the complexities by using natural languages queries.

The problem of design and implementation can be achieved with our proposal.

//List of your key findings

//The conclusion is an opportunity to succinctly answer the “So What?” question by placing the study within the context of how your research advances past research about the topic.

//Front end communication changed the communication type between backend and front end as an asynchronous communication. However, Scropopo ensures the asynchronous communication through a broker service that can be reachable by a web user.

//We showed the architecture would be useful for smart factories. Without SPARQL, the efficiency of human operators increases. The Difficulty of stream data queries is that a query delays sending a query until it gets an answer. This can be acceptable steps before query formulation causes delays.

// OPC UA Servers can be used with desktop applications instead of OPC UA Web-based software, however. However, major drawbacks are installation, admin-panel security, ineligible to use simultaneously.

//A Finding – Time limited JWT Authentication augmented with REST API can diminish the performance of web-based software and can block the session-based communication. Therefore, availability of a token must be more than session-state time.

// We proved that the information model and the address space of OPC UA Protocol are convenient to deploy with a semantic question answering. At the beginning of research, our initial question was like how could we send a natural query to an OPC UA Server.

//The limitation is data size and quality. We need more subject-predicate-object triples. More importantly, the data source of any smart factories should categorize and customize the predicates of triples according to the requirements of any smart factories. If so, we can implement algorithms that are more precisely such as deep learning or reinforcement learning methods to improve the quality of answers. Moreover, the system can be designed to show answers to reasoning questions. For instance, when a production machine created an error, a question answering system can answer questions regarding errors.

//Synchronous calls are not suitable for OPC UA Web-based communication. Creating threads for every session created by an external user might lead to a single point of failure because of the synchronization of threads. We offered non-blocking I/O queues to queue every request by implementing quasi-asynchronous calls. Even if a web-based software created with asynchronous calls, it balances the load of requests to stave off a single point of failure or failure state. On the other hand, a discovery server can complete the architecture in terms of Service Oriented Architecture. Our approach handles the communication between client-server architecture hard-coded endpoints. A discovery service would be more convenient in remote communication connected with multiple OPC UA Servers. Finding endpoints and sharing certificates become significant in the existence of inter-smart factories.

//Provide a solution synchronous components of web-based software would be broker based non-blocking input output queue. (Message oriented middleware)

//The hardest part was --- integration of streamed data key-value mapper, find a way querying into OPC UA Servers, reducing the average request time with a properly selected algorithm,

//Monitored item node can be better represented if we use aggregation server in the architecture. Aggregated server can be integrated to Dynamic Server and all sessions detached to create one big address space.

//The major findings are that the proposed novel approach can be used efficiently to create an assistance tool for manufacturing technologies and synthesized theory caters a robust architecture for the aimed platform.

//The semantic question answering is not useful for mission-critical systems. The solution of this problem a template based query generation can be enforced.

## 8 CONCLUSION

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//Instead of creating a new application for instant semantic linked data, OPC UA Servers can shape the data, however, it is cumbersome and time-wasting objective. At a limited phase, one can utilize for the linked data concept, but the generalization of this application is not possible because of the structures of every OPC UA Servers.

- 1) Conclusions: concise statements about your main findings, related to your aims/objectives/hypothesis

- 1) What should (and should not) be in the conclusion?
- 2) How long should it be?
- 3) What am I trying to say in my conclusion?

What should not be in the conclusion?

- 1) Discussion: This should be in the Discussion section. If your thesis combines the two, use sub-headings to distinguish between them
- 2) Any points that have not been mentioned in the Discussion section; your conclusions should be based only on points already raised.
- 3) References: It is quite unusual to include references in this section, as it is mainly a review of what has already been said.
- 4) Unnecessary information: your conclusion should be concise.

How long should my conclusion be?

The length of your conclusion will depend on a number of variables,

Check with your supervisor and with highly regarded past theses.

What am I trying to say in my conclusion?

What are you trying to say?

What I did learn?

What am I proudest of?

What was the hardest part?

How did I solve the difficulty?

Alternatively, in other words:

- 1) To what extent you achieved your aims/objectives OR not; if not, why not?
- 2) How important and significant your results are, as well as any limitations of your research (e.g. small sample size, other variables)
- 3) Where the research should go from here: what are some interesting further areas to be explored based on what you discovered or proven?

//All research questions in the section named Scope and Methods. Answer all of them



## 8.2 Future Works

- 2) Future Research: Where to go from here (can include where NOT to go, if your research demonstrated that a particular approach or avenue was not useful)

The devices that connected to OPC UA are growing day by day and requirements are expanded according to new requirements of smart factories. Experts need more tools that can take natural input by giving a scientific output. In order to provide this, linked data sources should be more capable of representing internal devices, actuators, and sensors. Such HMI devices connected to a remote domain of a smart factory need a more complex discovery service like Global Discovery Service. A Global Discovery Service can handle certificate management between local and remote domain through a certificate distribution. So each device can authenticate through a global discovery service and OPC UA Clients can easily find endpoints of OPC UA Servers. OPC UA Servers can change data inside and enlarge with a hierarchical structure of a smart factory. To serialize such changes requires a continuous serialization process; however, a continuous SPARQL language can detect the triples on updated roots of OPC UA Servers. Many different serializations of OPC UA static data has been left for further development due to architectural difficulties. KVIN Service could be turned into a continuous SPARQL endpoint instead of key-value storage.

//Named Entity Recognition can customize for company needs.

//Aggregated Server for general requirements for Smart Factory and for monitoring nodes.

//Abbreviation Checker can be handled

//Linked Data Efficiency will be improved. Especially, we can add more properties and corresponding explanations through the linkedfactory web page.

//A microservice architecture can be planned

//Reason induction system can be added if more data would be provided

//A machine learning system based on deep learning can be implemented if we get more data that generated by Fraunhofer IWU.

---

```
//Spell Checker has been implemented  
//In a particular range of time, a user send a real time query against KVIN Service.  
//Non Blocking IO Queue (e.g. Rabbitmq can be added to balance load)  
//Sparql endpoint of KVIN should comply with the param  
http://domain.com:10080/sparql/endpoint&{SPARQL Query}  
//Multiple federated query support with “SERVICE” statement can be extended with the  
new version. SPARQL GRAPH statement can be extended in accordance with Update
```

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## Appendix A Linked Data

### A.1 Manually Developed Test Questions – Precision and Recall

| Question  | ID | Precision | Recall |
|---|----|-----------|--------|
| What do linkedfactory, heatmeter, and e3fabrik incorporate exactly?                                 | 1  | 0         | 0      |
| Provide me a combined result for IWU and e3sim  | 2  | 1.0       | 1.0    |
| I want to know which one carries fofab?   | 3  | 1.0       | 1.0    |
| There is a member named fofab. Please give me all of its members                                    | 4  | 1.0       | 1.0    |
| I am a customer for this company. Could you tell me please what the value of sensor1 of machine1 is | 5  | 0         | 0      |
| Could you tell me please what is the current value of sensor2 in machine2?                          | 6  | 1.0       | 1.0    |
| What POWERMETER holds?  | 7  | 1.0       | 1.0    |
| What does FOFAB incorporate?  | 8  | 1.0       | 1.0    |
| What does machine5 HOLD?  | 9  | 1.0       | 1.0    |
| What does gmx comprise?   | 10 | 1.0       | 1.0    |
| What comprises karobau?   | 11 | 0         | 0      |
| System health for sensor2 in machine6   | 12 | 1.0       | 1.0    |

---

|   |    |     |     |
|---|----|-----|-----|
| <b>Tell me the health of system<br/>for sensor2 in machine1</b>                           | 13 | 0.0 | 0.0 |
| <b>Could you browse generated data?</b>   | 14 | 1.0 | 1.0 |
| <b>Give me all of the members<br/>of gmxspanen4</b>                                       | 15 | 0.0 | 0.0 |
| <b>What holds coolingwater?</b>   | 16 | 1.0 | 1.0 |
| <b>What is the hierarchical<br/>structure of fofab?</b>                                   | 17 | 1.0 | 1.0 |
| <b>What contains IWU?</b>   | 18 | A   | B   |
| <b>Could you give me the<br/>members in which contained by versuchsfeld?</b>              | 19 | 1.0 | 1.0 |
| <b>Could you give me the<br/>members in which<br/>linkedfactory has?</b>                  | 20 | A   | B   |
| <b>What is the value of sensor1<br/>in machine6?</b>                                      | 21 | 1.0 | 1.0 |
| <b>What is minimum that we<br/>can calculate for sensor1 of<br/>machine1?</b>             | 22 | 1.0 | 1.0 |
| <b>What is the value of maximum<br/>can be calculated by<br/>the sensor1 of machine1?</b> | 23 | 1.0 | 1.0 |
| <b>Could you tell me what the<br/>average for sensor3 in machine1 is?</b>                 | 24 | 1.0 | 1.0 |
| <b>I need to learn an average<br/>value for sensor5 in machine2</b>                       | 25 | 0.0 | 0.0 |
| <b>What is the average of sensor3 in machine3?</b>  | 26 | A   | B   |

|  |    |     |     |
|--|----|-----|-----|
| <b>Could you get me the references of nodes?</b>                       | 27 | A   | B   |
| <b>Could you browse generated data?</b>                                | 28 | A   | B   |
| <b>Is the E3-Sim member of linkedfactory?</b>                          | 29 | 0.0 | 0.0 |
| <b>Could you take me all members of generated data?</b>                | 30 | A   | B   |
| <b>Give me all registered node id</b>                                  | 31 | A   | B   |
| <b>I need to learn parent node id in generated data</b>                | 32 | A   | B   |
| <b>Could you give me parent node id in the file of generated data?</b> | 33 | A   | B   |
| <b>Give me all data blocks</b>   | 34 | A   | B   |
| <b>Data blocks in generated OPC file</b>                               | 35 | A   | B   |
| <b>Give me the name of stations in generated data</b>                  | 36 | A   | B   |
| <b>All stations which are in generated data or new data</b>            | 37 | A   | B   |
| <b>Please combined result of datablock, station</b>                    | 38 | A   | B   |
| <b>Who is Fofab?</b>   | 39 | 0.0 | 0.0 |
| <b>Why can all nodes be browsed?</b>                                   | 40 | 0.0 | 0.0 |

Table 0.1: Precision and Recall of Answers

---

## A.2 Natural Language Understanding Libraries

**TextBlob:** TextBlob is a tool based NLTK to process a natural query without providing NLTK's function overhead. It was written in Python 2 but also compatible with the Python 3 version. It provides a simple API for diving into common tasks of Natural Language Processing such as part-of-speech tagging, sentiment analysis, classification etc.<sup>11</sup>

**Stanford CoreNLP:** One of the fastest and robust libraries for Natural Language Processing provided by Stanford University. The only drawback of this library is limited support for Python programming language. However, it has been solved this problem with Rest – Compatible Web service by sending external HTTP queries from Python programming language. Stanford CoreNLP works based on Java Virtual Machine so that it can be conceptualized as model-view-controller pattern. As shown in Figure 1.1, Stanford CoreNLP supports diversity of implementation that is a vital role for natural language processing. Stanford CoreNLP provides an API which annotation-based that suitable underlying models or resource are available for the different languages [67]. The main drawback of CoreNLP is that one needs to use other programming languages except for Java by wrapping up Java compiled packages to specific languages. This reduces supports of full-feature such as sentiment analysis, dcoref, regexner<sup>12</sup>.

**Spacy:** It is an open source library for Natural Language Processing which is written in Python and C-counterpart Cython<sup>13</sup> It utilizes the convolutional neural model for tagging, parsing, and entity recognition to increase the precision of findings in natural language processing. When a request is sent to spacy, it calls a language pipeline, which it is brought into line tokenizer, tagger, parser, and named-entity recognition respectively.

**AllenNLP:** It is a scientific based NLP library compatible with Python. AllenNLP also provides a demo tool which has used in this work to demonstrate the development steps of NLP. AllenNLP has advanced features to use that not only industrial scale application but also scientific purpose tools such as coreference resolution, semantic role labeling, open information extraction or textual entailment.

---

<sup>11</sup> <https://textblob.readthedocs.io/en/dev/>

<sup>12</sup> <https://github.com/Lynten/stanford-corenlp>

<sup>13</sup> <https://spacy.io/api/>

**SyntaxNet:** It is a library provided by Google that works with a deep neural network based on Tensorflow. The main purpose of this library is to serve as a syntactic parser. Moreover, this library focuses on dependency parsing more than constituency parser.

**Natural Language Toolkit:** NLTK is one of the fundamental languages that consists of many features such as tokenization, parsing, tagging published as an open source project.

| Libraries               | Advantages   | Disadvantages   |
|-------------------------|--|---|
| <b>TextBlob</b>         | Low overhead while doing a natural language understanding    | Only windows based service setup,   |
| <b>Stanford CoreNLP</b> | Strong support for variety of languages                      | Central Point of Failure, Bottleneck if there is not enough maintenance   |
| <b>Spacy</b>            | Easy to use with web platform technologies                   | Dependency on Node Virtual Machine and npm package manager<br>Pipelining creates repercuSSION in NLP<br>Limited Architecture Support(64 bit OS) |
| <b>AllenNLP</b>         | Large supported-features for Natural Language Processing     | No support for windows  |
| <b>SyntaxNet</b>        | Purely Deep Learning Based<br>Stack based dependency parsing | No backward compatible.<br>No asynchronous support for the language version.<br>Python 2.x  |

Table 0.2: NLP Toolkits Advantages and Drawbacks

---

### A.3 KVIN Service Sample Query

Query

---

Model  
<http://linkedfactory.iwu.fraunhofer.de/data/>

---

Query

```
select * where {
service <kvin:> {
<http://localhost:10080/linkedfactory/demofactory/machine1/sensor1>
<http://example.org/value> ?v . ?v <kvin:limit> 1 ; <kvin:value> ?value
}
}
```

---

The SPARQL query.

**Submit**

Figure 0.1: Enilink Sample SPARQL Query

### A.4 KVIN Service Result of Appendix A.4 with a Key-Value Pair

| Result              |                   |
|---------------------|-------------------|
| v                   | value             |
| :node1cvr8o4kfx2005 | 2.142857142857143 |

Figure 0.2: A result from a continuous data

## A.5 Serialized Streaming Data into Linked Data

```

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
@prefix : <http://example.org/data/values.csv#>.

<http://linkedfactory.iwu.fraunhofer.de/linkedfactory/values.csv#row=1>
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#time> "2018-09-
28T06:49:16.9230000+00:00"^^xsd:dateTime;
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#value>
8.142857142857142.
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory/values.csv#row=10>
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#time> "2018-09-
28T06:49:43.9260000+00:00"^^xsd:dateTime;
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#value>
8.166666666666666.
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory/values.csv#row=100>
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#time> "2018-09-
28T06:54:13.9650000+00:00"^^xsd:dateTime;
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#value>
8.166666666666666.
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory/values.csv#row=1000
>
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#time> "2018-09-
28T07:39:14.3010000+00:00"^^xsd:dateTime;
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory#value>
4.166666666666667.
<http://linkedfactory.iwu.fraunhofer.de/linkedfactory/values.csv#row=101>
```

Listing 0.1: Generated RDF from Real-Time Data Source

---

## A.6 Serialized Static Data

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .  
@prefix : <http://opcfoundation.org/UA/2011/03/UANodeSet.xsd#> .  
  
<unknown:namespace> :UANodeSet <unknown:namespace#UANodeSet> .  
  
<unknown:namespace#UANodeSet> :NamespaceUris  
<unknown:namespace#UANodeSet/NamespaceUris> .  
  
<unknown:namespace#UANodeSet/NamespaceUris> :Uri  
<unknown:namespace#UANodeSet/NamespaceUris/Uri> .  
  
<unknown:namespace#UANodeSet/NamespaceUris/Uri> rdf:value  
"http://opcfoundation.org/iwu/DynamicServer" .  
  
<unknown:namespace#UANodeSet/NamespaceUris> rdf:_1  
<unknown:namespace#UANodeSet/NamespaceUris/Uri> ;  
    :Uri <unknown:namespace#UANodeSet/NamespaceUris/Uri_2> .  
  
<unknown:namespace#UANodeSet/NamespaceUris/Uri_2> rdf:value  
"http://opcfoundation.org/UA/Diagnostics" .  
  
<unknown:namespace#UANodeSet/NamespaceUris> rdf:_2  
<unknown:namespace#UANodeSet/NamespaceUris/Uri_2> .
```

Listing 0.2: Preview of Generated Semantic Data from an OPC UA Server

## A.7 KVIN Streaming Data SPARQL Service

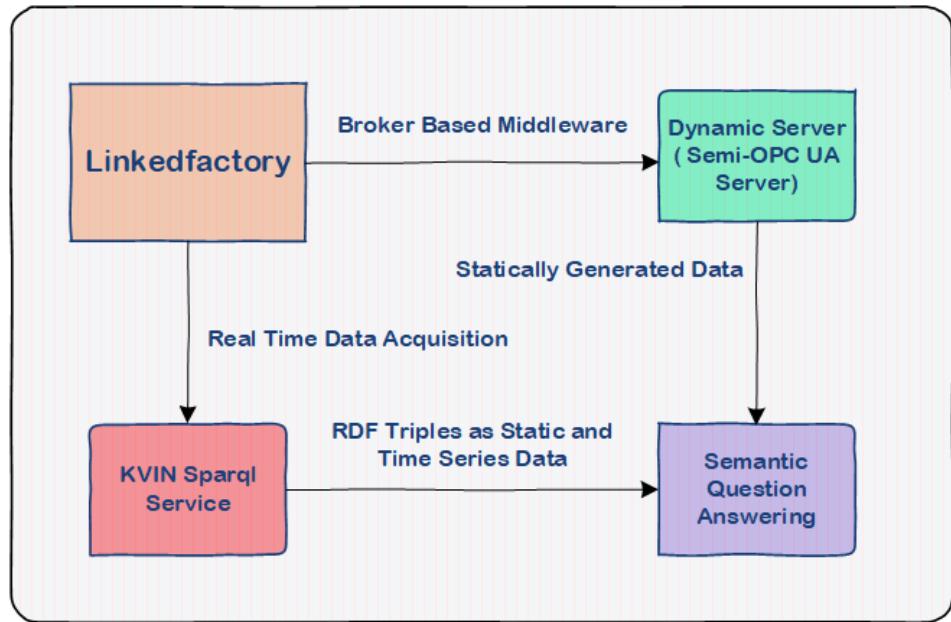


Figure 0.3: General KVIN Service

## A.8 eniLINK Prefixes

```

@prefix : <enilink:model:users#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
  
```

Listing 0.3: Enilink Sample Prefixes

## A.9 Deep Parsing-Shallow Parsing

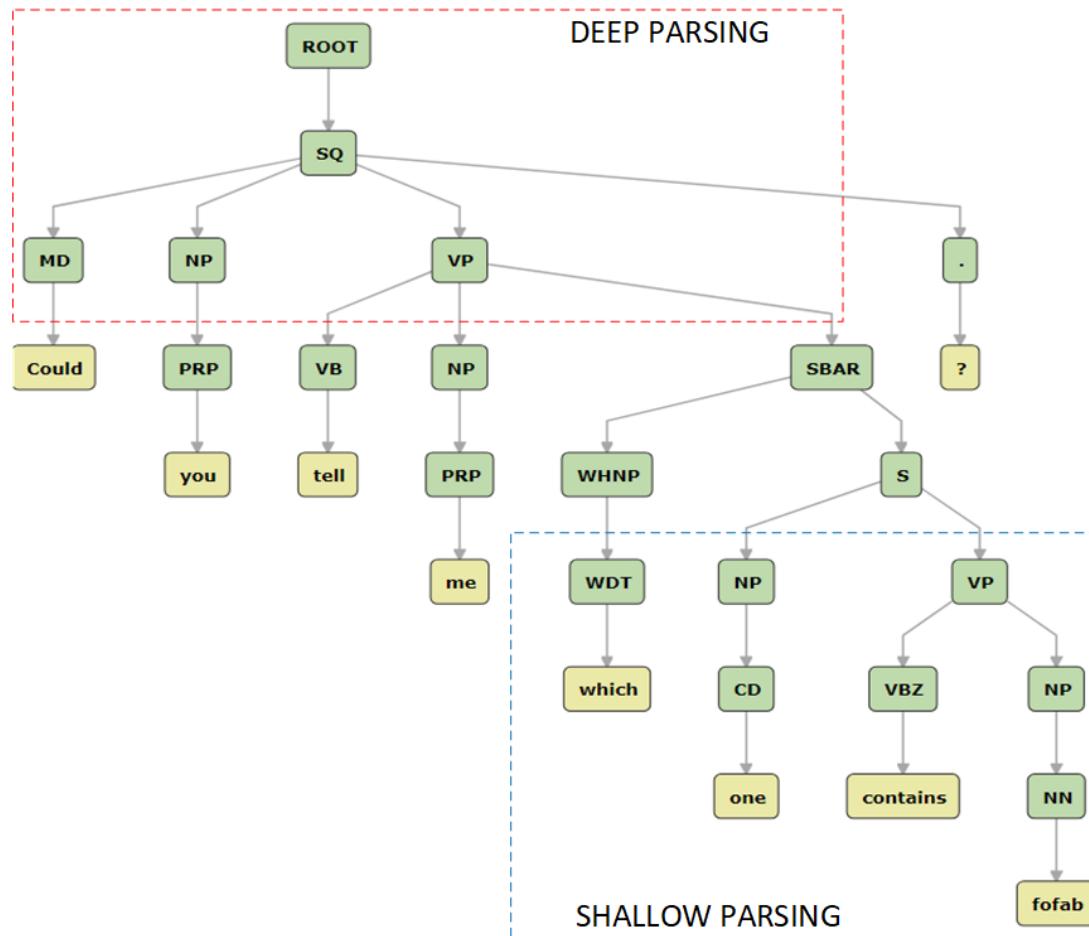


Figure 0.4: Constituency parse tree for factoid question

## A.10 Generated Answer from OPC UA Information Modeling

```
(rdflib.term.Literal(u'linkedfactory.iwu.fraunhofer.de/linkedfactory/demofactory/machine1/sensor5')),)
(rdflib.term.Literal(u'AnonymousIdentityToken')),)
(rdflib.term.Literal(u'When the action triggering the event occurred.')),)
(rdflib.term.Literal(u'linkedfactory.iwu.fraunhofer.de/linkedfactory/IWU/RolleX/PowerMeter')),)
(rdflib.term.Literal(u'Reports diagnostics about the server.')),)
(rdflib.term.Literal(u'ns=1;s=root_Demo_Scalar_SByte')),)
(rdflib.term.Literal(u'A numeric identifier for an object.')),)
(rdflib.term.Literal(u'i=2403')),)
(rdflib.term.Literal(u'Pure Python Client')),)
(rdflib.term.Literal(u'ns=2;i=1075791275')),)
(rdflib.term.Literal(u'i=11891')),)
(rdflib.term.Literal(u'i=3181')),)
(rdflib.term.Literal(u'i=290')),)
(rdflib.term.Literal(u'i=3094')),)
(rdflib.term.Literal(u'ns=1;s=root_linkedfactory.iwu.fraunhofer.de_linkedfactory_demofactory_machine2_sensor7_value')),)
(rdflib.term.Literal(u'The type for non-looping hierarchical references that are used to define sub types.')),)
(rdflib.term.Literal(u'i=11737')),)
(rdflib.term.Literal(u'An object that represents a file that can be accessed via the server.')),)
(rdflib.term.Literal(u'i=298')),)
```

Listing 0.4: An answer from generated OPC UA Semantic Data

---

## Appendix B Web Development

### B.1 CoffeeScript Sample

```
SDNEntity = require('./SDNEntity.js')
_ = require('underscore')
uuid = require('uuid')
config = require('../config.js')
request = require('request')

class SDNController extends SDNEntity
  controllers = []

  constructor: (@uReg) ->
    @controllerID = 2000
```

Listing 0.5: A sample from Coffeescript

## B.2 JavaScript Counterpart of the CoffeeScript Sample

```
(function() {
  var SDNController, SDNEntity, config, request, uuid,_,
    _bind = function(fn, me){ return function(){ return
fn.apply(me, arguments); }; },
    _hasProp = {}.hasOwnProperty,
    _extends = function(child, parent) { for (var key in
parent) { if (_hasProp.call(parent, key)) child[key] =
parent[key]; } function ctor() { this.constructor = child; }
ctor.prototype = parent.prototype; child.prototype = new
ctor(); child._super_ = parent.prototype; return child; };

  SDNEntity = require('./SDNEntity.js');

  _ = require('underscore');

  uuid = require('uuid');

  config = require('../config.js');

  request = require('request');

  SDNController = (function(_super) {
    var controllers;

    _extends(SDNController, _super);

    controllers = [];
  });
}
```

Listing 0.6: Counterpart of sample CoffeeScript in Figure 1.1

## B.3 Script Languages for User Interface Development

Fundamentally, script languages are a subset of programming languages. The front-end framework coherently work with script languages. Notwithstanding, a crucial step sets script languages apart programming languages, which is at the compilation level. Script languages rather interpret where implemented.

**JavaScript:** JavaScript is an entry point for Rich Internet Application, which provides a content-rich application to an end-user. Event handler concept started with JavaScript

---

language. The functional programming paradigm started with JavaScript for script languages. ECMA Standard is a de facto standard of JavaScript and these properties affect other languages that based on JavaScript language features. Such features include hoisting, callback functions, promises, lazy evaluations, generators, asynchronous iteration, and advanced regular expressions.

**TypeScript:** Typescript is an object-oriented version of JavaScript and pretty much closer to JavaScript language. According to the essential characteristics of JavaScript, it should provide a functional language that supports callback functions without object and class. Javascript libraries can be compiled within Typescript language without occurring any problem. TypeScript sets apart from JavaScript with an object-oriented paradigm, static typing, and compile time type checking. Thus, TypeScript is a statically typed language because it should compile all types in compile-time to check the correctness of data. However, JavaScript is a dynamically typed language, which a dynamically typed language should have an interpreter layer, not a compiled one. TypeScript can implement object-oriented paradigms such as interfaces, classes, abstract classes or objects.

**CoffeeScript:** It is kind of similar context with JavaScript but it gives a concise and compact structure when compared to JavaScript. CoffeeScript reduces coding time thanks to short-cut version of its language property but the drawback of CoffeeScript is that needs a step to compile from CoffeeScript to JavaScript. After conversion to Coffescrit, it makes look complicated than Javascript because of pre-processor codes. Basically, Coffeescript reduces code complexity (Counterpart stuff) but it makes a harder syntactic structure for a JavaScript Developer. While Coffeescript is suitable for small module development which can easily be integrated into a bigger module, JavaScript and TypeScript can handle with a large scale of a code base. It makes available to enable an object-oriented script development like TypeScript contrary to JavaScript language.

**PureScript:** It is one of the largest cross-compiler support as compared to the last three. PureScript aims to be a language in front-end technologies. Large scalability support is one of the fundamental features of PureScript. It can be used in multiple operating systems, C and Field Programmable Gate Array. As compared to other script languages, PureScript has the largest scalability support for multiple platforms. This script language is based on Haskell Functional Programming Language. PureScript support polyglot programming, for instance, a core part of an application could be written in PureScript as well as JavaScript could be used for another module. By using Records can be handled with more complex Object structures in PureScript. PureScript can modify Classes and

instances with keywords with “class” and “instance” by creating advanced typed-data. The type definition is more enhanced than JavaScript because PureScript can preserve data with keywords and it is an *indentation-sensitive*, unlike other script languages. It provides worker threads, which is reducing the number of threads by putting all into a pool mechanism in order to use in case of need.

## B.4 Publish/Subscribe Service

This service defines the way of communication by using message-oriented architecture or standard transmission protocol of Open Systems Interconnection. By utilizing a middleware, publisher and subscriber can be de-coupled. Subscriber or Publisher may be an OPC UA Server to transmit information to clients; however, a severe weakness with this method is a necessity to write values temporarily to the address space. Due to the installation of broker infrastructure, message-oriented service brings more cost to any architecture. In the literature, middleware of Publish/Subscribe Service breaks up two various titles, which is Broker-Based Middleware and Broker-less Middleware [68]. It is generally accepted that the broker-based middleware has a common use in industrial internet of things. The fundamental characteristics of the broker-based are detaching different protocols from each other through a broker, confidentiality between publisher and subscriber, and integrity can be ensured among publisher-subscriber pairs.

Dynamic Server uses message-oriented architecture, and it behaves as a publisher. Hence, it designed differently from other OPC UA Server to takes messages that can be dispatched to particular receivers. Although the fundamental data collector is eniLINK with sensors, Dynamic Server sends a list of values with timestamps and topics to subscribers conveniently. This communication occurs asynchronously because synchronous communication is not suitable for a broker unless it has a non-blocking input-output queue. Through the message broker architecture as depicted in Figure 3-3, each flow of OPC UA can transmit via a non-blocking queue, which is the fundamental step for asynchronous communication. As shown in Table 3-1, the pros and cons have been listed so that broker-based architecture reduces the latency of streamed data to store data into any source such as cloud service or real-time database without loss. The generated data set from Dynamic Server defines a structure through its Information Model and this model contains data from sensors and actuators that connect to eniLINK. Message Broker Service collects data from production and manufacturing system in the smart factory of Fraunhofer in helping the creation of linked data.

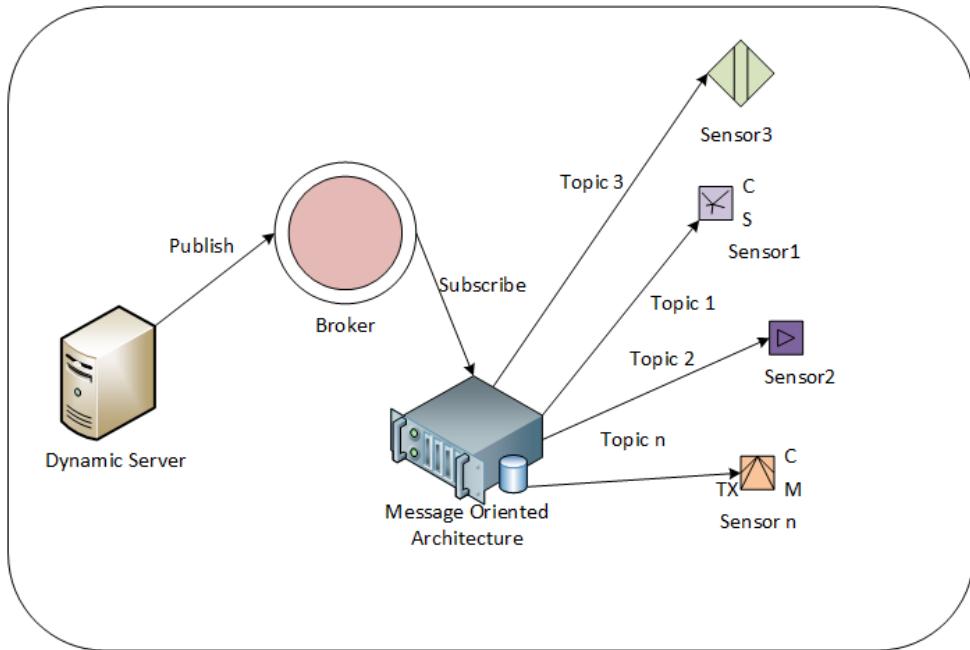


Figure 0.5: The Dynamic Server Publish/Subscribe Model

| Types of Middleware            | Advantages  | Disadvantages   |
|--------------------------------|---|---|
| <b>Broker-less Middleware</b>  | <ul style="list-style-type: none"> <li>• No Central Point of Failure,</li> <li>• Legacy Devices Support</li> <li>• No additional software components like Broker</li> </ul> | <ul style="list-style-type: none"> <li>• Protocol Dependency because of non-existence a Broker</li> </ul> |
| <b>Broker-based Middleware</b> | <ul style="list-style-type: none"> <li>• Broker reduces latency and overhead generally</li> </ul>   | <ul style="list-style-type: none"> <li>• A network bottleneck could be disastrous</li> </ul>              |

Table 0.3: Types of Middleware Publish/Subscribe

## B.5 OPC Unified Architecture Information Model Serialization Algorithm

---

**Algorithm 1** Node Extraction
 

---

```

1: function MAINFUNCTION()                                ▷ Starting point
2:   export = ServerExport(serverurl, filename)
3:   export.IMPORT NODES(serverurl)
4:   export.EXPORT FILE(outputFile, namespaces)
5: function BUILD NODE TREE(nodes)                      ▷ Node Formatting
6:   client ← GETENDPOINT()
7:   client ← CLIENT(serverurl)
8:   nodecumulated ←None
9:   nodeID ←0
10:  for node < nodes do
11:    nodecumulated = node.nodeid.Namespaceindex
12:    for ref < node.getreferences() do
13:      nodecumulated.extend( ref.nodeid.Namespaceindex)
14:    nodecumulated = list(set(nodcumulated))  ▷ Clear duplicates
15:  return nodeID                                     ▷ Return node id list
16: function IMPORT NODES(serverurl)                   ▷ Traverse Node
17:   client = Client(serverurl)
18:   client.connect()
19:   for ns < client.getNamespaces() do
20:     namespaces[client.getNamespaceIndex(ns)] = ns
21:   root = client.getRootNode()
22:   child = client.iterateChildNodes()
23: function EXPORT FILE(outputFile, namespaces = None) ▷ Export into XML
24:   if namespaces != None then
25:     for node != nodes do
26:       if node.nodeid.namespaceindex is namespaces
27:         nodes = [node]
28:       else
29:         nodes = list(nodes)
30:
31:   export = XmlExport(client) then
32:     export.BUILD NODE(nodes)
33:     export.appendXML(outputFile)
34:
  
```

---

Figure 0.6: Extraction Algorithm of OPC UA Address Space

## B.6 Backend Framework Comparison

| Criteria                              | ASP.NET Core                           | Spring IO                               | Django Framework  | Node.js                                | Flask                 |
|---------------------------------------|--|---|---|--|-----------------------|
| <b>Multiple Queries</b>               | 46.4%                                  | 13.6%                                   | %3.63   | 24.9%                                  | 21.7%                 |
| <b>Latency of Multiple Queries</b>    | 0.5 ms                                 | 80.9 ms                                 | 287.8 ms  | 44.4 ms                                | 226 ms                |
| <b>Platform Support</b>               | All Platform                           | All Platform                            | All Platform  | All Platform                           | All Platform          |
| <b>JSON Serialization</b>             | 80.8%                                  | %8.7                                    | %10.8   | %46.7                                  | 12.2%                 |
| <b>Latency of JSON Serialization</b>  | 0.6 ms                                 | 4.8 ms                                  | 5.8 ms  | 0.9 ms                                 | 3.8 ms                |
| <b>Single Queries</b>                 | 54.9%                                  | 12.8%                                   | 3.7%  | 28.7%                                  | 10.8%                 |
| <b>Latency of Single Queries</b>      | 0.5 ms                                 | 3.8 ms                                  | 1.4 ms  | 0.4 ms                                 | 3.5 ms                |
| <b>Plaintext Query</b>                | 99.7%                                  | 2.3 %                                   | 2.1%  | 12.7%                                  | 4.1%                  |
| <b>The latency of Plaintext Query</b> | 1.4 ms                                 | 397.7 ms                                | 24.1 ms   | 65.9 ms                                | 45.8 ms               |
| <b>Compatibility</b>                  | Backend Compatible with minor versions | Backward Compatible with minor versions | No Backward Compatibility between Python 2.7 and Python 3.0 | Backend compatible with major versions | No Backend Compatible |

Table 0.4: Backend Development Framework

## B.7 Frontend Framework Comparison

| Feature                   | Angular 2  | React                   | Ember.js         | MeteorJS         | VueJS            |
|---------------------------|--|-------------------------|------------------|------------------|------------------|
| <b>Dynamic UI Binding</b> | B2   | B3                      | Doldur           | Doldur           | Doldur           |
| <b>Reusable Component</b> | +  | +                       | +                | Doldur           | Doldur           |
| <b>Routing</b>            | Async Routing  |                         |                  |                  |                  |
| <b>Data binding</b>       | Doldur   | State binding           | One-way bindings | Template Binding | Two-way bindings |
| <b>Performance</b>        |  |                         |                  |                  |                  |
| <b>Feature Advantage</b>  | Object-oriented script development, Independent Library Dependency | Token Interceptor       |                  |                  |                  |
| <b>Dependent Pattern</b>  | Model-View-Component   | Component-based Archute |                  |                  |                  |

Table 0.5: Script Languages

---

## B.8 Load Balancer&Reverse Proxy Configuration

```
ssl_certificate ..../cert.pem;
ssl_certificate_key ..../cert.key;
location / {
    try_files $uri $uri/ @mongrel;
}

location /integratedstaticmessage {
    try_files $uri $uri/ @questionmodule;
}
location /integrateddynamicmessage {
    try_files $uri $uri/ @questionmodule;
}
location /fraunhoferengine {
    try_files $uri $uri/ @questionmodule;
}
location @mongrel {
    proxy_http_version 1.1;
    proxy_pass http://backend;
}

location @questionmodule {
    proxy_http_version 1.1;
    proxy_pass http://questionanswering;
}
}

upstream backend {
#max_fails=3 fail_timeout=60s
least_conn;
#server 127.0.0.1:4002 weight=5;
#server 127.0.0.1:4003 weight=4;
#server 127.0.0.1:4001 weight=3;
#server 127.0.0.1:4000 weight=2;
server 127.0.0.1:4002;
server 127.0.0.1:4003;
server 127.0.0.1:4001;
server 127.0.0.1:4000;
}

upstream questionanswering {
least_conn;
server 127.0.0.1:5000;
server 127.0.0.1:4999;
}
```

Figure 0.7: Sample configuration of a load balancer





## Glossary

**Softmax Layer:** It is a regression-based result to assign a multi-classification machine learning problem.

**Inter-process Communication:**

**Machine Learning:** It is the science of getting computers to act without being explicitly programmed.

**Reinforcement Learning:** It is a type of Machine Learning Algorithms which allows software agents and machines to automatically determine the ideal behavior within a specific context, to maximize its performance.

**Long Short Term Memory:** LSTM is a unit of recurrent neural network which composed of a cell, an input gate, an output gate and a forget gate.

**Bi-directional Long Short Term Memory:** A bidirectional LSTM layer learns bidirectional long-term dependencies between time steps of time series or sequence data.

**Word Vector Representation:** It is a word vector in a row of real valued numbers

**Recurrent Neural Network:** It is a subclass of artificial neural network where connections between nodes from a directed graph or directed acyclic graph along a sequence.

**Stanford CoreNLP Tokenization:** It provides a tool that tokenizes a text snippet or blob of text

**Stanford CoreNLP Part of Speech Tagger (POS Tagger):** It provides a tool of which labels tokens with their part of speech tag

**Neural Machine Translation:** It is an end-to-end learning approach for automated translation, with the potential to overcome many of the weaknesses of conventional phrase-based translation systems.

**Epoch:** This term explains that is single pass through whole training dataset







## **Selbstständigkeitserklärung**

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig angefertigt, nicht anderweitig zu Prüfungszwecken vorgelegt und keine anderen als die angegebenen Hilfsmittel verwendet habe. Sämtliche wissentlich verwendete Textausschnitte, Zitate oder Inhalte anderer Verfasser wurden ausdrücklich als solche gekennzeichnet.

Chemnitz, den 11. March 2019

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[Comments] Orcun Oruc

TODO: Es wird empfohlen die offizielle Selbständigkeitserklärung des ZPAs zu verwenden: <http://www.tu-chemnitz.de/verwaltung/studentenamt/zpa/formulare/Allgemein/allgemein/selbststaendigkeitserklaerung.pdf>