A Semantic Multi-Agent Architecture for Multilingual Machine Translation

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***Abstract*- Machine Translation is the use of computerized methods to automate all or part of the translation process from one natural language into another. Machine Translation systems used to overcome the language barriers, for example, by making digital information understandable to people across the world in minimum amount of time. A Multi-agent system is a software system that consists of multiple active, task-oriented and autonomous intelligent agents. Such agents can communicate and coordinate between each other in order to produce high quality solutions to complex problems in different domains. The semantic web is realized by adding semantics to the web in which it gives well-defined semantic meaning of information. It makes it possible to facilitate the representation, interpretation, sharing, searching, and reusing of information. This paper proposes a Semantic Multi-Agent Architecture for Multilingual Machine Translation system. In the proposed architecture, the multi-agent technology and ontologies will be integrated to produce collaborative working environment for multilingual machine translation. The automatic reasoning capacity of agents and their collaboration will improve the quality of the translation process. While, the incorporation of semantic features of languages, using ontologies, can be effective in increasing the quality of translations as such features focus more on the intended meaning of words rather than their syntactical structure.**

I. Introduction

Machine Translation (MT) System is software system that produces translations, with or without human assistance, from one natural language into another. It produces translation throughout three main steps including the analysis of text of the source language, translation of text in the source language and generation of the text in the target language. These steps are essential to grasp the syntax, morphology and semantic features of two languages [1]. Although, MT systems can generate translations more cheaper and quickly than human translators; the quality of MT systems is less than the quality of human translation [2].

A software agent is an active and task-oriented software entity that performs tasks and cooperates with other agents to achieve their intended objectives. An agent has the capability to flexibly and autonomously perform in the environment where it is placed. Multi-agent system (MAS) is a network of software agents that are communicating and coordinating within each other to achieve specific goals that cannot be accomplished by a single agent. MAS exploits the power of knowledge sharing and exchange as key strategy for complex problem solving [3]. In terms of the development of MAS, there are currently a number of available general purpose frameworks and toolkits that provide standardization of the development of MAS and save time and effort of developers. Most of these frameworks are particularly developed to create simulations of complex systems and general purpose applications. Natural language processing, in particular, MT may benefit from the use of multiple agents that can work together to improve the translation process [1, 4]. However, to the best of our knowledge, there are limited researches in the area of using MAS in natural language processing, in particular, MT. Accordingly, much more research is needed to further develop and refine the area of using multi-agent technology for MT.

As defined by Tim Berners-Lee, "The Semantic Web is what we will get if we perform the same globalization process to Knowledge Representation that the Web initially did to Hypertext" [5]. The Semantic Web considered as an expansion of the existing Web in which information can give an unambiguous meaning, so that people and

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computers can work and cooperate with each other effectively [6]. The semantic web is realized by adding semantics to the web in which it gives information a well-defined semantic meaning, so it makes it possible to facilitate information representing, interpreting, searching, sharing and reusing [7]. In particular, ontologies have been commonly employed as a way of providing the semantics to retain the retrieval information based on the intentional meaning more willingly than basically matching the search terms [3]. However, it has been proven that incorporating the semantic features of languages via ontologies in MT systems can effectively increase the quality of translations as such features can model relationships that are not realized from syntactic structures [2].

To this end, this paper reports the design of a Semantic Multi-Agent Architecture which is designed to develop Multilingual MT systems. In the proposed architecture, Multi-agent technology and ontologies will be incorporated to produce collaborative working environment for Multilingual MT. The automatic reasoning capacity of agents and their collaboration will improve the quality of translation process. Whereas, the use of ontologies has the benefit of translating the inputted text from the source to the target languages based on the intentional meaning rather than simply match the inputted terms based on their syntactic structure. The reminder of this paper is organized as follows: Section 2 presents an overview of the research background and related works. The proposed Semantic Multi-Agent Architecture is described in Section 3. Finally, conclusion and future works are discussed in Section 4.

II. Background and Related works

A. *Multilingual Machine Translation*

Machine Translation (MT) systems are software systems used to produce text or speech translations from one natural language to another with or without human support. It is a challenging and demanding task to develop a MT system for a variety of languages with limited electronic tools and resources. MT systems can be: 1) bilingual systems which are particularly designed for two particular languages, or 2) multilingual systems which are particularly designed for more than a single pair of languages. A bilingual system may be either from one Source Language (SL) into one Target Language (TL), called unidirectional MT system, or may be from one Source Language (SL) into one Target Language (TL), and vice versa, called bidirectional MT system. Most bilingual systems are unidirectional, but multilingual systems are generally designed to be bidirectional [8].

MT systems can be categorized according to the use of traditional or modern technology and by which means they perform translation. MT systems can be classified into Direct MT, Rule based Translation, Corpus based Translation, and Knowledge based Translation [9, 10].

1) *Direct MT*

In direct MT systems, a source language is translated directly into another language in which a direct word by word translation of the input source is performed with or without maintaining the sense of the word. Direct translation requires a bilingual dictionary as well as a morphological word analyzer. In direct MT, the translator replaces the corresponding word in the target language dictionary without taking into account any grammatical rules. The direct MT is unidirectional and it takes only one single pair of languages into account simultaneously [9, 10].

2) *Rule based translation*

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In rule-based MT systems, the source language text is parsed and an intermediate representation is created, then the intermediate representation is translated into the target language. Rule based MT system can be additionally classified into Transfer based MT and Interlingua based MT. In the Transfer based MT, a set of linguistic rules is used to translate text from source to target language to preserve the meaning of a sentence. When sentences go with one of the transfer rules, it is translated directly using a dictionary. Transfer rules are realized by analyzing the grammatical structures of both the source and target languages. In the Interlingua based MT, the source language is converted into an intermediary universal language, called Interlingua, then Interlingua is translated to more than one target language [9, 10].

3) Corpus based translation

Corpus based MT is promising and becoming a very popular translation approach in today's world. Corpus based MT requires a huge dataset since it is based on a corpus to perform a statistical analysis of source and target languages. Corpus based MT system can be additionally classified into statistical based MT and example based MT. The statistical based MT is based on the statistical models which are extracted from the corpus of both the source and target languages. The statistical models, for translating from the source language to the target language, are created using supervised or unsupervised statistical machine learning algorithms as well as some statistical information such as the characteristics of the sentences of the source and target languages. The example based MT preserves a corpus consisting of a set of translation examples between source and target languages. Firstly, it retrieves a comparable sentence and its translation from the corpus, then it adapts the retrieved translation to obtain the final proper translation [9,10].

4) Knowledge based translation

There was a limited semantic analysis in early MT systems which mostly consider the use of syntax. Language analysis using semantic based approaches have been recently introduced. Knowledge based MT requires a large knowledge base that consist of both lexical and ontological knowledge [9, 10].

Among the successful implementation of MT systems, a number of recent studies on Multilingual MT have been proposed [11-13]. Wibawa et al. [11] proposed a multilingual MT system which integrates the example-based MT (EBMT) and statistical MT (SMT) approaches. The proposed system helps Javanese[1] youths in translating between one of the four speech levels of Javanese to Indonesian language or vice versa. The experimental evaluation demonstrates that the Javanese-Indonesian translation is more accurate (average accuracy is 0.83%) than the Indonesian-Javanese translation (average accuracy is 0.68%). The authors argue that the accuracy of the proposed multilingual MT system can be improved by increasing the size of training data. On the other hand, Meera and Sony [12] presented a solution that relies on rule based direct MT system to translate a source English language into a target Malayalam and Hindi languages using a bilingual dictionary. In their implemented algorithm, they combined the first order predicate logic (FOPL) based semantic checking with a word sense disambiguation. The algorithm starts with defining the rules, then using Weka software to crate training sentences. The authors crated huge amount of training sentences for the purpose of increasing efficiency. The authors used the precision and recall formulas to evaluate the proposed algorithm. The results showed an accuracy of 74%. Authors suggested that the improvement

[1] https://en.wikipedia.org/wiki/Javanese_language

of the results can be achieved by more morphological inflections to the system. More recently, Choi et al. [13] developed a multilingual MT system to offer overseas tourists, in the 2018 Winter Olympic Games that will be held in Korea, with a multilingual speech translation service. The authors apply crowdsourcing translation using the existing large Korean-English corpus to create Korean-English-French and Korean-English-Spanish triangle corpus with minimum cost and time. However, authors notice very many translation errors from the triangle corpora. Therefore, a semi-automatic filtering of translation errors in large triangle corpus is proposed to resolve the translation loss caused by crowdsourcing translation.

B. Multi-Agent Systems

A Multi-agent system is a software system that consists of a number of interacting intelligent agents and their environment. Coordination, and communication between agents create quality solutions that cannot be produced by a single agent in its *own capacity*. Multi-agent systems use search algorithms, procedural and functional approaches to solve problems that are very difficult for ordinary systems to solve. Knowledge and messages sharing, parse the messages, and understand messages are the features of multi-agents that enable them to socially communicate and behave in an intelligent way. Multi-agent interaction and knowledge sharing constitute a dynamic topology that changes each time to interact with the new environment to solve the challenging problem [14].

In terms of the development of Multi-agent System, there are currently a number of available general purpose frameworks and toolkits that provide standardization of the development of multi-agent system and save time and effort of developers. Examples of the standard Multi-agent System development frameworks are Jason[2], JADE[3], SeSAm[4], and AgentBuilder[5]. Most of these frameworks are particularly developed to create simulations of complex systems and general purpose applications. However, none of the mentioned frameworks has been dedicated for the natural language processing research area, in particular, MT [1]. Accordingly, much more research is needed to further develop and refine the area of using multi-agent technology for MT.

The development of natural language processing applications, specifically MT systems, using the Multi-agent technology has gained little attention among the research community in which a limited number of studies have been proposed[1, 4, 15]. Aref [4] proposed multi-agent system techniques for natural language understanding. The purpose of using multi agent system (MAS) is to exploit the resources and capabilities of the interconnected agents. The author introduced decentralized MAS system that overcomes the single point failure essential to centralized systems and other resources and performance limitations. The system combined lexical and cognitive structural approach to design an understating multi-agent system. The system consists of two types of agents: the first is a lexical agent that contains the English vocabulary with all their linguistic information. The other is a cognitive structural agent that consists of six modules: Speech-to-text, Text-to-speech, Morphological, Semantic, Discourse, and Query Analyzers. These agents communicate with user input to simulate the answer for user questions. The authors implemented and tested the modules separately, and waived the integration between modules and user interface for future work. Minakow et al. [15] exploit the Multi-agent technology to develop a text understanding

[2] The Jason framework: http://jason.sourceforge.net/wp/
[3] The JADE framework: http://jade.tilab.com/
[4] The SeSAm framework: http://www.simsesam.de/

system for car insurance. The proposed Multi-agent system includes four steps: 1) morphological analysis, 2) syntax analysis, 3) semantic analysis and 4) pragmatics. The process starts by dividing the whole text into sentences, and then the first three steps are applied to each sentence for meaning extraction. Finally, the parsed text enters the final step – pragmatics. Hettige et al. [1] design and implement a Java based Multi-agent System for Machine Translation, known as MaSMT, which supports English to Sinhala languages machine translations. MaSMT includes two types of agents, specifically ordinary agents and manager agents. That control ordinary agents. A number of ordinary agents in the swarm are assigned to a specific manager agent to be within its control. Manager agents can directly communicate within each other and within its controlled ordinary agents. Ordinary agents can only directly communicate within each other in its own swarm and with its manager agent. The system framework implements object-object communication, MySQL database connectivity and XML-based data passing for message passing. Agent communication in the system framework conforms with the specification of the Agent Communication Language (ACL)[6] defined by FIPA (Foundation for Intelligent Physical Agents). Experimental results demonstrate that the MaSMT can be employed to develop successful natural language processing applications.

C. Semantic Web and Ontologies

The Semantic Web is a framework that uses standards developed by the WWW Consortium to support common exchange protocols and data formats on the Web. Semantic web standardizing allows data to be reused and shared across application, enterprise, and community boundaries. The semantic web core is ontology, which is supported by languages such as RDF and OWL. In computer science, ontology define the specification of a conceptualization by facilitating explicitly the knowledge reuse [16]. There important aspects are needed to explicitly realize the ontology languages [16]:

1) Conceptualization: through selecting a suitable reference model such as entity-relationship model, it provides ontology construct to define the entities and relations and the relation between entities.
2) Vocabulary: the language should also include the syntax and grammars.
3) Axiomatization: rules, constraints and factual knowledge are required to capture the semantics for inference.

The Semantic Web architecture is composed of several layers. One of the most important is the ontology layer. Ontology is knowledge representations, containing words and statements that specify the semantics of a given knowledge domain in a given operational environment. The ontology takes the structure of a directed graph (nodes and arcs). Nodes represent concepts and edges represent the semantic relationships between those concepts. To exploit the ontology by a machine, certain rules must be respected, as the definition of a formal syntax and unambiguous semantics, and deduction of new knowledge presented implicitly in the ontology [17, 18]. In order to facilitate sharing activities and collaboration between agents, web based knowledge agrees on common and explicit ontologies [16]. Explicit ontologies facilitate the following features [16]:

1) Interoperability as specified by W3C.
2) Extensibility. This concept relies on developing the ontologies incrementally using reusability concept.

[5] The AgentBuilder framework: http://www.agentbuilder.com/Documentation/Lite/
[6] FIPA-ACL Specifications, Available at: http://www.fipa.org/repository/aclspecs.html

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3) Visibility. To be able to understand the knowledge written in an unfamiliar language, common ontological on syntax and semantics is required.
4) Inferenceability. The ontology enables logical inference on facts through axiomatization.

The knowledge resulted in the ontology are conveyed using a number of components or brick base, which are mainly: 1) Concepts, 2) Relationship, 3) Functions 4) Axioms, and 5) Instances [19, 20].

The Resource Description Framework (RDF) and the Web Ontology Language (OWL) are two main standard languages. These languages facilitate the process of data and knowledge sharing and integration for easing the web-accessible information and services. The RDF is a language that facilitates information integration by allowing the use of Internationalized Resource Identifiers (IRIs) - a generalization of Uniform Resource Locators (URLs) - to refer to resources. Because of the RDF constraints (i.e., RDF doesn't has the ability to describe cardinality constraints), the need for more expressive ontology language is recognized. The OWL extends the RDF standard by processing the information content instead of just presenting information to humans. The OWL has more facilities in expressing meaning and representing machine interpretable content on the Web compared with other standard languages [16, 21]. To create, update, delete, maintain, communicate with ontology we can use the protégé tool, it is a free, open-source ontology editor and framework for building intelligent systems. The protégé supports OWL and RDF ontology languages [22].

There are a number of studies, that integrate the use of semantic web technologies with multi-agent systems, have been proposed [23-27]. In the paper by Williams [23], the DOGGIE agent is proposed to address the ontology problem in a multi-agent system made up of agents with diverse ontologies. Using a machine-learning algorithm, the author describes how the agents learn representations of their own ontologies and how the agents teach each other what their concepts mean. The author introduces a methodology based on agents on the semantic web that deals with the knowledge sharing issues resulting from diverse ontologies. More complex ontologies are planned to be carried out. Aref and Zhou [24] used the newly OWL standardized technique to construct the Multi-Agent communication and work. The authors concentrated on implementing a MultiAgent system that enables them to capture the meaning of the text using natural language understanding. The authors used four criteria to evaluate the developed MultiAgent system: representational adequacy, inferential adequacy, inferential efficiency and acquisitional efficiency. The results show that the developed system is not able to optimize all criteria. In spite of this, using OWL as a standard has a potential future in the field of language translation. Another research paper proposed by García-Sánchez et al. [25] discusses the main purpose of using semantic web technologies with multi-agent systems, in the biomedical research area, which is the increasing demand of data integration. The authors presented SEMMAS system, an ontology-based and domain independent framework that works on integrating intelligent agent and semantic web. The authors pointed out that improved data integration methods are required, and control mechanisms for data redundancy and inconsistency are needed. Lee & Wang [26] proposed an ontology-based computational intelligent multi-agent system for Capability Maturity Model Integration (CMMI) assessment. A CMMI ontology that represents the CMMI domain knowledge is predefined by domain experts to be utilized by the computational intelligent multi-agent system. The proposed system includes a natural language processing agent, an ontological reasoning agent and a summary agent. These agents cooperate with one another to accomplish the goal of effectively

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summarizing the evaluation reports for the CMMI assessment. Hakansson et al. [27] presented a multi-agent system that uses ontology as an interface to search for a user request. Once the ontology found, the agent bring back its location and the systems complete the missing information. The multi-agents are coordinated by meta-agents. Meta-agents perform the mapping between ontologies and language translation and reason for the validity of the returned contents. The authors applied the presented MAS system in e-tourism domain. The testing results showed that the system is still at a primitive level, therefore the translation and domain definition must be handled by a reliable tool instead of using Google translate and general domain.

To summarize, there are very relatively little research effort in the area of using MAS and ontologies in MT. For that reason, this research is important to advance the current development of this area of research.

III. The proposed Semantic Multi-Agent Architecture for Multilingual MT

The proposed architecture of Multilingual MT system, as shown by Fig. 1, consists of two major components: User Interface and Translation. Each component represents some of precise tasks realized by a number of autonomous agents. The process of the proposed system architecture starts by receiving a text (written in the source language) by the interface agent, thereafter, the text is subjected to different phases of analysis and communication with ontologies to generate a translation of the text in a target language.

A. *The user interface component*:

It contains two agents, as follows:

1) ***Interface Agent****:* this agent has specific tasks, which are:

- Receives the user request which includes: the text to translate, the source language, and the target language (Step 1 in Fig. 1). Then, it transfers these information to the lexical analyzer agent (Step 2 in Fig. 1).
- Displays to the user the resulting translated text in a target language (Step 7 in Fig. 1).

2) ***Language Recognition Agent***, this agent has specific tasks, which are:

- Recognizes the source language of a text, in case it isn't indicated in the user request, by matching the terms in the user request with the existing terms in a domain corpus or thesaurus of the source language (Step 1.1 in Fig. 1).
- Prompts the user for the target language in case it is not indicated in the user request.

B. *The translation component:*

It is the main part of the proposed architecture. It receives the user request and uses multi agents and source and target language ontologies to analysis the user text and translates it into the required target language.

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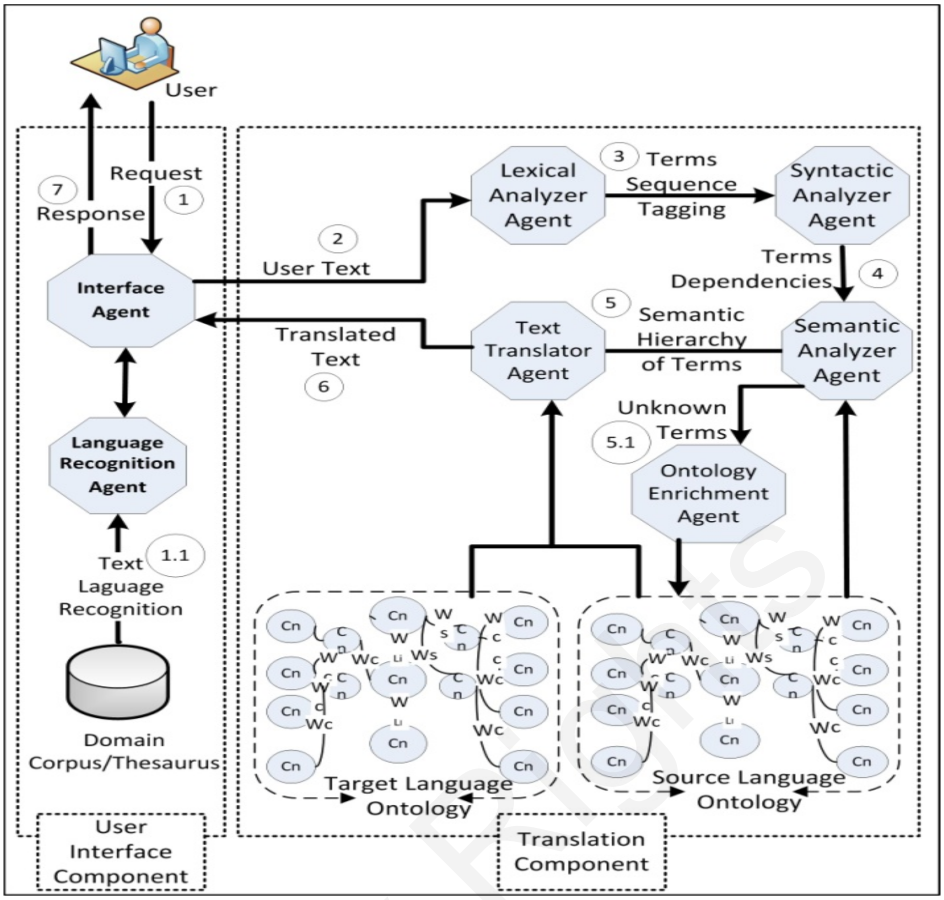

Fig 1. The Semantic Multi-gent Architecture for Multilingual MT

An Illustrative Example:

We present a helpful example to better understand the purpose and the task realized by each agent in the proposed architecture. Suppose a user asks the system to translate a sentence:

"***I am from Amman***"

Written by a user in English (Source language is indicated by the user), and we need to translate it into French language (Target language is indicated by the user).

The translation component contains five agents, as follows**:**

1) ***Lexical Analyzer Agent***, the main role of this agent is the extraction of a term sequence from the user text (on the source language). During the operation of the lexical analysis, the lexical analyzer agent eliminates all useless information: blanks, tabs, end of lines and line break...etc. Then it applies a segmentation process to separate words in order to extract the basic entities: name, verb, and adjective...etc. The TreeTagger software [28] can be used by this agent to accomplish such tasks. The main function of the TreeTagger is the lemmatization and automatic syntactical tag of the text. The output of the TreeTagger is a tagged terms sequence by basics entities: verbs, names..etc. (Step 3 in Fig. 1) (see example in Table1).

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TABLE1: THE TAGGING PROCESS OF THE GIVEN EXAMPLE USING THE TREETAGGER TOOL. PP: PERSONAL PRONOUN, VRB: VERB, DET: DESCRIPTIVE / QUALIFICATIVE ADJECTIVE. NOM: COMMON AND PROPER NOUNS.

Term	I	am	from	Amman
Tag	PP	VRB:Present	DET	NOM

*2) **Syntactic Analyzer Agent***, the main role of this agent is the verification of the conformity of the terms sequences of the basics entities, generated by the Lexical Analyzer agent, with the grammar rules that describe the source language. This agent generates as output a terms dependencies tree of the user text (Step 2 in Fig. 1) (see example in Fig. 2). To identify the syntactical relationships between terms, the syntactic analysis tool uses morpho-syntactic rules that describing the constraints in which a text must follow to be identified.

When a morpho-syntactic rule is identified in the text between two terms, it points out the presence of a relationship between these two terms.

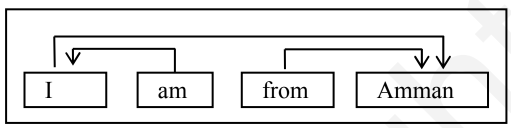

Fig. 2: Syntactic terms dependencies tree of the given example.

Syntactic Analyzer agent can use an automatic syntactic analysis tool, for example, the Stanford parser [29] that is a dedicated software to provide a dependency hierarchy in English language. It allows the automatic creation of syntactic terms dependencies tree based on a set of grammatical and syntactic analysis rules (see Fig. 2). The Stanford parser returns a complete syntactic terms dependencies tree in which the terms are connected by syntactic relations.

*3) **Semantic Analyzer Agent***, the main role of this agent is to understand the sequence of terms based on the syntactic terms dependencies tree provided by the Syntactic Analyzer agent in source language (Step 5 in Fig. 1). This agent identifies the semantic concept, in the source language ontology, of each term in the dependencies tree. To better detect the semantic of a term and its corresponding semantic concept, the term context must be investigated. In general, ontologies are used to assure this type of process. A semantic analyzer tool [30, 31] can be used by the Semantic Analyzer agent. It receives the syntactic terms dependencies tree and determines the possible contexts of each term using the source language ontology

The semantic concept hierarchy is constructed via the mapping between the terms and their corresponding concepts, and the syntactic relationships of terms and their corresponding relationships, in the source language ontology. In case there are terms that don’t correspond to any concept in the source language ontology, these terms are considered as unknown terms and they will be sent to the Ontology Enrichment agent (Step 5.1 in Fig. 1). As output, the Semantic Analyzer agent returns a concept semantic hierarchy of the inputted terms (see Fig. 3).

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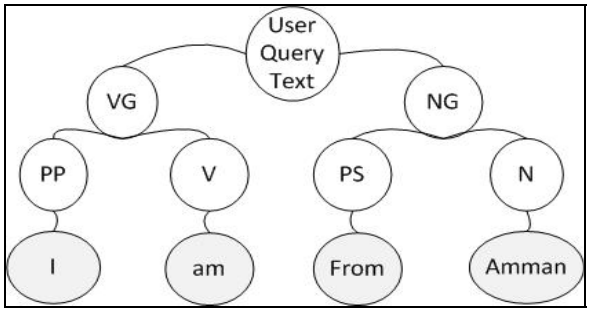

Fig. 3: Semantic concept hierarchy of the given example. VG: Verbal Group, PP: Personal Pronoun, NG: Nominal Group, PS: Preposition Spatial, V: Verb, N: Common and proper nouns.

*4) **Text Translator Agent***, the main role of this agent is to receive a semantic concept hierarchy expressed on the source language, and produces as output a translated text in target language (Step 6 in Fig. 1). The agent can use a multilingual ontology such as the WordNet ontology. The WordNet is based on the theories of knowledge representation: memorizing terms and concepts in a hierarchical manner, using the inclusion relationships. It divides the data into four databases organized differently from one another, associated with the names of categories, verbs, adjectives and adverbs. The names and verbs are organized into hierarchies. Relationships such as hyponymy ("is a") and hyponymy link names and verbs with their "specializations" [32-35].

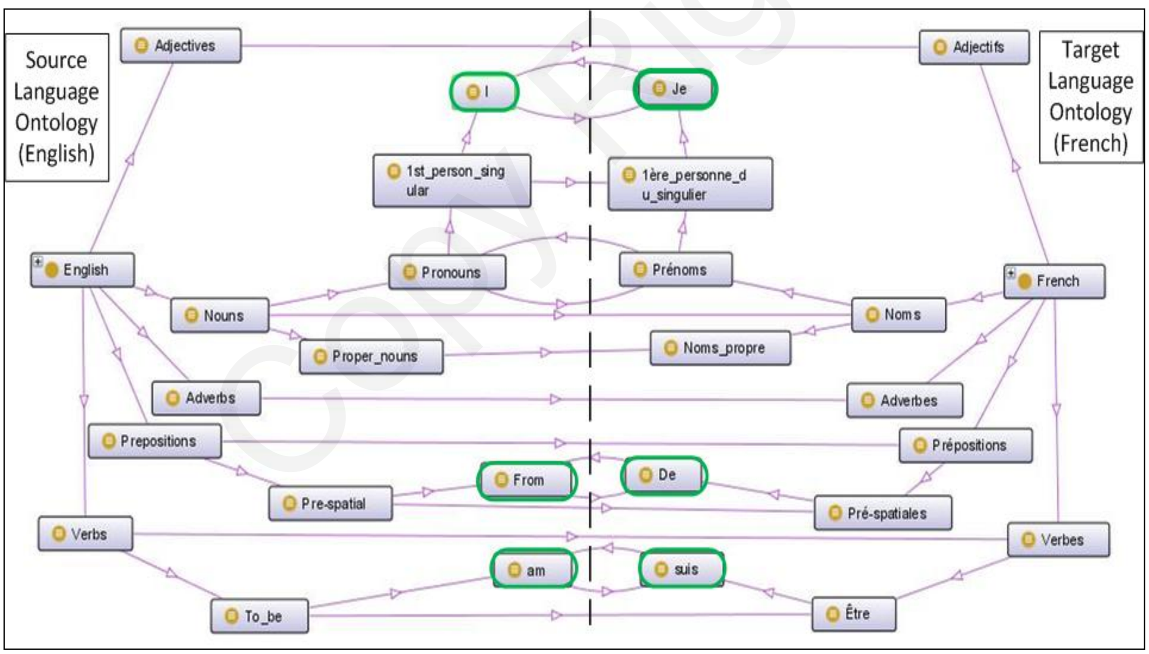

Fig. 4: The translation process of each concept, of the illustrative example, from the source to the target language using a multilingual ontology.

The main advantage of using the WordNet ontology is the fact that it is a multilingual representation of knowledge. This advantage allows the translation of the concepts and relationships from the source language to the target language. To translate the user text, the text translator agent must:

1. Translates each concept of the semantic concept hierarchy by its corresponding concept on the target language using a multilingual ontology such as the WordNet (see example in Fig. 4).
2. Transform the concept semantic hierarchy to a new translated text expressed using the target language. For example, the new translated text of the illustrative example in the French language will be:

"**Je suis d'Amman**"

3. Verify the lexical and syntactic syntax of the new translated text in accordance with the grammar rules of the target language.
4. Send the new translated text to the Interface agent.

5) ***Ontology Enrichment Agent***, the main role of this agent is the enrichment of the source language ontology with the unknown terms extracted by the semantic analyzer agent from the text to translate (Step 5.1 in Fig. 1). There are several methods for automatic ontology enrichment in the literature [36, 37]. Such methods are based on a minimum generic base of rules between terms. Initially, non-redundant terms are extracted from a source domain (like thesaurus, corpus). Then, the approximation of terms is performed through the mapping between concepts of the ontology and the new terms. For more details on this, refer to [36, 37].

IV. Conclusion

This paper has reported the design of the Semantic Multi-Agent Architecture for a Multilingual Machine Translation system. The proposed architecture integrates the Multi-agent technology and ontologies to produce collaborative working environment in order to improve the quality of the Multilingual MT. It consists of two major components: the User Interface and the Translation. Each component represents some of precise tasks realized by a number of autonomous agents. The User Interface component contains two agents: Interface agent, and Language Recognition agent. The Translation component consists of five agents: Lexical Analyzer agent, Syntactic Analyzer agent, Semantic Analyzer agent, Text Translator agent, and Ontology Enrichment agent. These agents are communicating with each other and with source and target language ontologies to capture the syntactic, morphology and semantic features of the source and target languages. The process of the proposed system architecture starts by receiving a text written in the source language by the interface agent as an input, and completes when the text translator agent successfully produces a translated text in target language as an output. Future study will focus on the implementation of a semantic multi-agent system for multilingual machine translation, and on the evaluation the proposed architecture.

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