Developing a Natural Language Understanding System for Dealing with the Sequencing Problem in Simulating Brain Damage

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Abstract: - This paper is an attempt to show how a Human-Robot Interface (HRI) system in the Greek language can help people with brain damage in speech and its related perception issues. This proposal is not the product of research conducted on how to treat brain injuries. It is a conclusion stemming from research on intelligent Human-Robot interfaces, as a part of Artificial Intelligence and Natural Language Processing, which approaches the processing and understanding of natural language with specific methods. For the same reason, experiments on real patients have not been conducted. Thus, this paper does not propose a competing method, but a method for further study. Since it is referring to a very general and quite complex issue, an approach is presented here for the Sequencing problem. A person with such a problem cannot hierarchically organize the tasks needed to be performed. This Hierarchy has to do with both time and practicality. The particular problem here, as much as the innovation of our approach, lies not when there are explicit temporally defined instructions, but in the ability to derive these temporal values through the person's perception from more vague temporal references. The present approach is developed based on our related previous works for deploying a robotic system that relies on Hole Semantics and the OMAS-III computational model as a grammatical formalism for its communication with humans.

Key-Words: NLP, NLG, NLU, dialog system, OMAS-III, HRI, Virtual Assistant, Hole Semantics, Sequencing.

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1 Introduction

In the research paper, [1] and its related work, the authors attempted to structure a Natural Language Processing (NLP) system based on a computational model called OMAS-III, [2]. OMAS-III is the third improved version of the original OMAS method, belonging to the family of SADT and IDEFx techniques, [3], [4], representing their design evolution. Here, OMAS-III is adapted to function as a grammatical formalism. This adaptation allows the detection of the grammatical position and value of words in a sentence, their correctness, and potential gaps in their grammatical structure, which, however, do not invalidate the sentence's correctness. The human brain can correctly fill in the gaps in elliptical structures. If this cannot be done due to ambiguities or non-grammatical expressions, it generates questions for the source (the interlocutor). Therefore, when this formalism detects gaps in the sentence to be processed, it generates basic questions for their completion. The entire endeavor is based on both OMAS-III and the Hole Semantics Theory, [5]. The study results demonstrated the algorithm's exceptional capabilities in processing incoming sentences, providing additional information due to OMAS-III that may be implicit or considered obvious in a dialogue. This information includes time and location as highly significant, while subject and object are considered less crucial.

The action is sufficient to be declared so that the algorithm begins to extract all the remaining information. If, for example, the verb was "come", then the algorithm understood that it was an imperative of the second person, so someone is calling you to go somewhere. As a grammatical sentence, it is correct, but because it's a machine, there are no obvious conclusions. So, what did the system want to know?

- Who is calling it to go?
- Where is it called to go?
- When should it go?
- How should it go (in what way)?

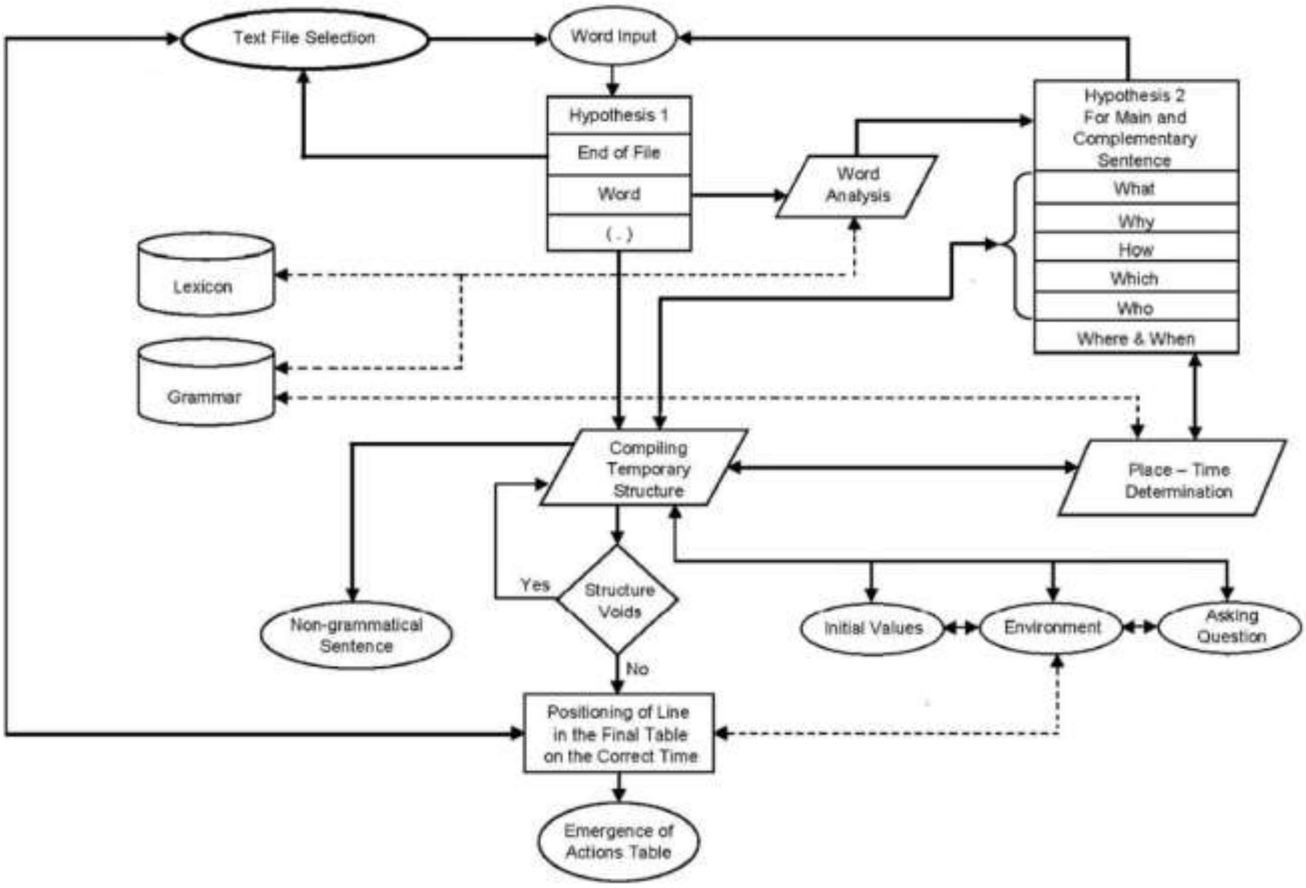

Fig. 1: Basic algorithm (from: [1], after adaptation)

Some of this information could be extracted by the algorithm from its database, as long as there was continuity in the dialogue, hence evolving knowledge and understanding. If the desired information was not in its database, then it posed all these questions to its interlocutor. Thus, in the "brain" of the system, a sentence was eventually formed: "The A person calls me to go to his/her point in a defined time." Through this algorithmic process, the system showed high "awareness", providing additional usability.

The algorithm, depicted in Figure 1, initially covers a broad spectrum. In continuation of the referenced work, a survey on Humanoid systems and their capabilities compared to humans was conducted, [6]. The conclusions highlighted the lack of implicit and obvious information reception, such as time and place perception. All systems were categorized based on the functions they cover. From there, a robotic system began to develop, aiming to cover all basic functions of a Humanoid from the outset, communicating and processing data in the Greek language. The initial algorithm allowed us to grab implied information such as time and place. In subsequent work, autonomous modules were added for additional functions, discovering that adding capabilities to the initial system is possible. The emerging idea is that, just as we can add capabilities, we can also remove them.

In recent work focused on the Natural Language Generation (NLG) module, [7], it was observed that the system could simulate certain brain impairments related to speech problems by removing modules and, conversely, complement brain functions related to speech by adding modules.

This paper does not constitute a survey on brain disorders related to speech. Therefore, some cases are briefly mentioned in a corresponding chapter. Through these cases, the impairment chosen to be approached has been identified and supported through this system.

The structure of the paper consists of six chapters. The first chapter is an introduction. The second chapter briefly discusses the grammatical formalism as designed with OMAS-III, the Hole semantic theory, and their combination. The third chapter discusses brain disorders related to speech and the specific case chosen herein to address through this system. The fourth chapter develops the method algorithm for the approach discussed in

Chapter 2. The fifth chapter discusses this developing system and how it provides possibilities for expanding its capabilities. The final, sixth, chapter presents conclusions and suggestions for future research.

2 OMAS-III & Hole Semantic Theory in Combination

In a few words, it will be described how OMAS-III contributes to the implementation of a grammatical formalism. In general, the algorithm based on OMAS-III seeks answers to the seven basic questions, known as “journalist questions”.

- The question “Why” will return the rationale (why). If there is an explanation of the action in the incoming sentence, it will be attributed to this question.
- The question “What” seeks the action referred to in the sentence, i.e., the verb itself.
- The question “How much” contains all the quantitative indicators, and the answer here is the objects of the sentence but not the adverbs.
- The question “How” seeks the method, indicating the action that will be used in the verb, and is done with the help of tropic adverbs and any determiners that can indicate manner.
- The question “Who” looks for the subject of the sentence.
- The question “Where” asks for the place where the verb will exert its action.
- The question “When” seeks the chronological moment when the action of the verb in the sentence will take place.

By answering these seven questions, this system gathers all the information provided. In cases where one or more of these questions are not answered, the algorithm turns to grammatical rules and the system’s database. If there are still gaps, the questions are externalized. These abilities are exhibited in the following examples.

Suppose our system is person A and is located at point 1. There is also a person B who is located at point 2. Another person submits the following sentence addressing the system: "A, go from point 1 to point 2, to meet B, now". The sentence enters the system and after being analyzed, it makes the following correspondences:
Who = "A";
What = "go";
How = with default moving way;
How Much = "B" (the object of the formalism);
Why = "to meet";
Where From = "point 1";
Where To = "point 2";
When = "now".
The above sentence is complete and answers all the formalism’s questions. Attention should be paid to the fact that the verb "go" indicates movement. So, since no way is stated, this movement will be done in the default way of the system, e.g., by its wheels. Also, the justification of the action (Why) is not mandatory, but since it is here we use it.
Now suppose that instead of the above sentence, the following sentence is submitted to the system (person A): "go to B".

The system now proceeds with the analysis as follows:

- Is there a verb? Yes! So: What = "go".
- Which tense? Present imperative. So: When = "now".
- Is there a subject? No! Who is it addressed to? Me! So: Who = "A".
- What action does the verb ask for? Movement! Does it indicate a way? No! So: How = moving by its default way.
- Has a movement been requested? Yes! Then,
  (a) Is the start point given? No! So: Where From = "A’s current position";
  (b) Is the end point given? No! Where To = (SEMANTIC) HOLE (required to be filled in).
- Is there an object? Yes! So: How Much = "B".
- Is a reason given? No. Not required! So: Why = "–".

At the end of the process we notice that all but one question has been completed! So, firstly the system tries to retrieve from its knowledge if the current position of "B" (Where To) is known. If it is not, then it submits a query to its originator to get this piece of information. Once it retrieves this piece of information as well, all queries will have been completed, as shown below:
Who = "A";
What = "go";
How = moving by default way;
How Much = "B";
Why = "-" (not required);
Where From = "A current position";
Where To = "B current position";
When = "now".

With the above example, we show how the used method can fill in incomplete grammatical structures, just like a human brain does. The answers to all these seven queries are the fillings in several holes that make up the grammatical formalism.

Given that Hole Semantics, [8], [9] is an approach in linguistics where holes represent the phonetic, morphological, syntactic and semantic levels of language, it can be said that it helps understand language as a complex system with various interacting levels while maintaining their autonomy. It is a framework that defines underspecified representations in arbitrary object languages such as FOL or DRT, [10], [11], [12], [13]. Specifically, it constructs an object language with holes to which other types can be attached.

The Hole Semantic Theory is applied to grammatical formalisms, as in this case, and as mentioned earlier. This theory also uses semantic grammar, [14], as it was done herein. More specifically, these grammars introduce artificial intelligence that makes the robot/machine capable of asking questions, and they are also constraint-based grammars, [15].

3 Encephalopathies Associated with Speech Disorders

In a research study from several years ago, the following statement was found: “Many problems related to the functions of the nervous system can be effectively studied through research on animals, which allows controlled and repeatable experiments on large groups of individuals. However, when we come to examine the relationship of the brain with language, we must recognize that our knowledge is entirely based on findings in humans”, [16]. At this very point, there could be an artificial brain that can replace the human brain for research purposes, offering what experimental animals provide for other functions. Let’s first look at some brain disorders related to speech disorders, some of which are included in the aforementioned research. We have the following cases: Dysphasia, Aphasia, and Alexia.

3.1 Dysphasia

In Dysphasia, patients are unable to articulate words correctly and, at the same time, comprehend the meanings of words. This language disorder is caused by damage to the part of the brain where language functions are concentrated. This damage can result from interrupted blood flow to the brain, infection, and swelling, head injury, or a tumor in the brain. Dysphasia leads a patient to difficulties in comprehension, as they are unable to recognize sounds, fail to understand and lose the meanings of words, cannot recall useful and non-useful information, and ultimately cannot recognize sentence structures during speech.

Other limitations include the ability to recognize what a word or sentence is but still unable to pronounce them, or substituting words or sounds while speaking. There may be cases where the patient can articulate basic words but cannot connect them into a grammatically correct sentence. Often, the patient gets stuck on a word or a sound and cannot clearly explain it in reading, as they struggle to recognize and understand letters and words. Additionally, due to the inability to remember information, results in problems with memories, recalling details from long narratives, and difficulties in understanding large sentences or forming letters. Furthermore, there is a problem even in organizing ideas into logical stories.

3.2 Aphasia

Aphasia is characterized by the inability to comprehend or produce written or spoken language. This term is used for severe language disorders, while Dysphasia is used for milder cases. It’s important to clarify that Aphasia is a symptom and not a disease, stemming from damage to the Wernicke and Broca areas of the brain. Aphasia has four forms of manifestation: non-fluent, fluent, global, and anomic, with conditions distinguished as acute, slowly worsening, and transient. Mixed forms often occur. Causes for the onset of Aphasia can include ischemic strokes, traumatic brain injuries, intracranial hemorrhages, intracranial tumors, neurodegenerative diseases, infections of the central nervous system, migraines with aura, or epileptic seizures. Explanatorily, the forms of aphasia are characterized by the following.

3.2.1 Non-Fluent Aphasia

In this form, speech is slow, and the “flow of speech” is disrupted, resulting in numerous syntactic errors. However, the comprehension of speech, whether oral or written, remains surprisingly good, as patients are aware of the problem and give the impression that they know what they want to say, but struggle to find the appropriate words to express it. Therefore, they can articulate better than a patient with dysarthria, as, in this case, they struggle to formulate sentences but do not make syntactic errors.

3.2.2 Fluent Aphasia

In this form, the main characteristic is the difficulty in understanding speech, where the patient has incomprehensible and fluent speech. In this case, the patient is unaware that others cannot understand them and presents an image of a person who constantly speaks with unintelligible words. This condition is located in the left temporal lobe in the Wernicke's area.

3.2.3 Global Aphasia

This specific form of aphasia is the most severe, characterized by deficits in both comprehension and speech production. Patients with Global Aphasia are mute and cannot even understand simple commands or sentences. These deficits are located in the left hemisphere of the brain, and in some cases, coexist with weakness in the right half of the body.

3.2.4 Anomic Aphasia

Defined as the mildest of the previous forms, individuals with Anomic Aphasia have difficulty finding appropriate words and use circumlocutory or explanatory speech to make their conversation partner understand which word they mean. A characteristic example is the claims of such patients, stating that they are imprisoned inside their heads or "I knew what I wanted to say, but I couldn't find the words to express it," or "Really, I understood everything, but I couldn't articulate my thoughts into words."

3.3 Alexia

The Alexia syndrome, otherwise known as Agraphia, is defined as a pathological entity in which the patient, without difficulties in oral or written speech, experiences difficulties in reading and comprehending written language. The patient communicates and understands oral speech encouragingly, although there are some deficiencies in words and pathological changes. They can write, but with some distortions in letters and spelling, without, however, depriving them of the ability to express in writing what they have thought to say or what has been asked of them. The area where the patient presents difficulty is in reading something suggested to them or in understanding a written text or phrase. Something quite common is the difficulties faced in understanding oral speech.

The damage in this syndrome is located in the posterior and upper regions of the occipital lobe. The occipital lobe is a crucial node, connected to the parietal and temporal lobes. Initially, its location led to the belief that it consisted of sensory types of Aphasia, as Wernicke stated until it was explained as a syndrome by Dejerine. Any damage in the upper region of the angular gyrus causes difficulties in information exchange between the two cerebral hemispheres, that is, the exchange between the symbolic image of a word and the spatial image of it at the reading level on paper.

A significant piece of information for a patient with Alexia syndrome is whether they are literate or illiterate. In literate individuals, the symptoms are very noticeable, and in the initial stages, there is difficulty in orally expressing certain words, giving the impression that they do not remember the word. In such cases, it is possible to be perceived as Amnesic Aphasia, something that, according to the above explanation, does not exist. Such cases reveal that it is not Amnesic Aphasia, as the phenomenon where the patient does not remember the word gradually recedes, until it is eliminated, resulting in no recurrence of such a phenomenon.

3.4 Hierarchical Task Structure (Sequencing)

In another research paper, it can be read, among other things: "This finding further supports the hypothesis that Broca's area could play a key role in encoding the hierarchical structure or, in other words, the motor syntax, of human actions", [17]. We encountered problems in Broca's area in subsection 3.2, which refers to Aphasia. This specific issue, where persons struggle to structure tasks that they are called to perform hierarchically, is referred to as a sequencing problem. We will delve into this particular issue because it is believed that we can propose a functional approach to support individuals with this problem. The role aimed to be played in this medical section is not an attempt to cure with artificial intelligence. It is simply wanted to create a mechanism in the form of an assistant to complement the individual, with this mechanism taking on the task of hierarchy. The sequence of tasks that someone needs to execute is related not only to time but also to another factor. This factor depends on both the importance of a task compared to another and a practical sequential connection between them. For example, if we have three tasks where:

1. Something needs to be done in Area A.
2. Something needs to be done in Area B.
3. Something else needs to be done in Area A.

It is logical for tasks in Area A to be done together. If the task in Area B is more important, then it should be done first. A healthy brain categorizes tasks by calculating these parameters, ultimately providing a chronological placement for task execution. Therefore, task sequencing ultimately involves the temporal arrangement of tasks. This developing system has the capability, as presented, to receive temporal parameters from incoming sentences, because it is a gap that needs to be filled. One of the basic functions of the core algorithm is the temporal placement of sentences after processing. Such a system, in the form of a smart virtual assistant, could receive incoming sentences, hierarchically organize them temporally, and suggest the order for the individual to follow in task execution. Current virtual assistants do not provide such capabilities.

3.5 A Hierarchy Example

Let's look at an example where a healthy brain prioritizes tasks it has to perform. In a multinational company, one of the employees is assigned a series of tasks where they need to:

Draft a report on the new product before taking a break. Upon returning from the break, go to the marketing office. Collect new documents from the director's office and bring the presentations recorded by the marketing office. Before leaving for the day, ensure that the financial amounts calculated by the accountants in the morning are correct.

The prioritization is as follows:

- First, they must draft the report on the new product and finish it before the break.
- When they return from the break, they need to pass by the marketing office.Collect the presentations.
- Then go to the director's office.
- Knock on the door.
- Hand over the new documents.
- Then present the marketing office's presentations.
- As they leave, close the door.
- Their last obligation is to visit the accounting department.
- Count the money.
- Ensure it is the correct result.
- After that, they can leave for the day.

4 Method / Algorithm

The method being developed here is an algorithm that will examine sentences already prioritized to submit them to the person who needs assistance. It is important to note again here that the chronological arrangement of all sentences based on qualitative and temporal characteristics is a default process performed by this developing system. Additionally, for the submission of sentences to humans, the natural language generation algorithm is activated, designed as an additional module for this system, [7].

Before proceeding with the algorithm development, we need to establish some basic characteristics regarding the grammar being used.

4.1 Grammatical Specifications

We will examine and determine how sentences regarding human tasks will reach the assistant robot, so that the assistant, in turn, can transfer them hierarchically to the user.

4.1.1 The Assistant Receives Sentences from the Command Giver

In this case, the sentences are formulated in the third person, since the command giver addresses the recipient through the assistant. Besides performing the required prioritization, the assistant must also change the sentence from the third to the second person. Thus, if the command from the giver is: "He needs to complete this Task," the transfer from the assistant to the recipient will be: "You need to complete this Task." In the Greek language, verbs change when the person changes, and this is something we must consider in the algorithm design.

4.1.2 The Assistant Simply Listens to Sentences from the Command Giver to the Recipient

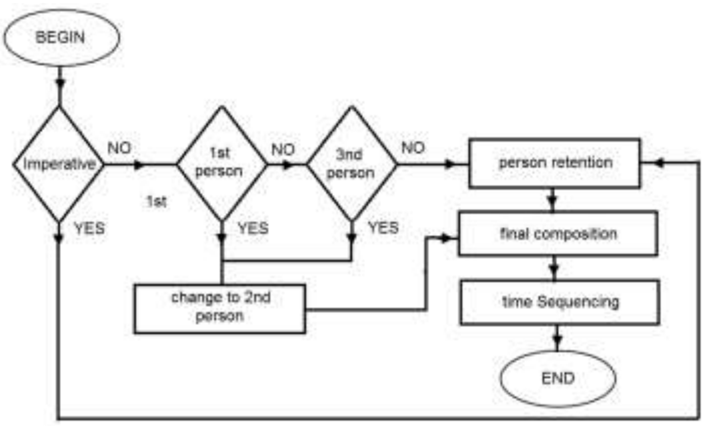

Fig. 2: the algorithm to support people who have sequencing problems in task hierarchy

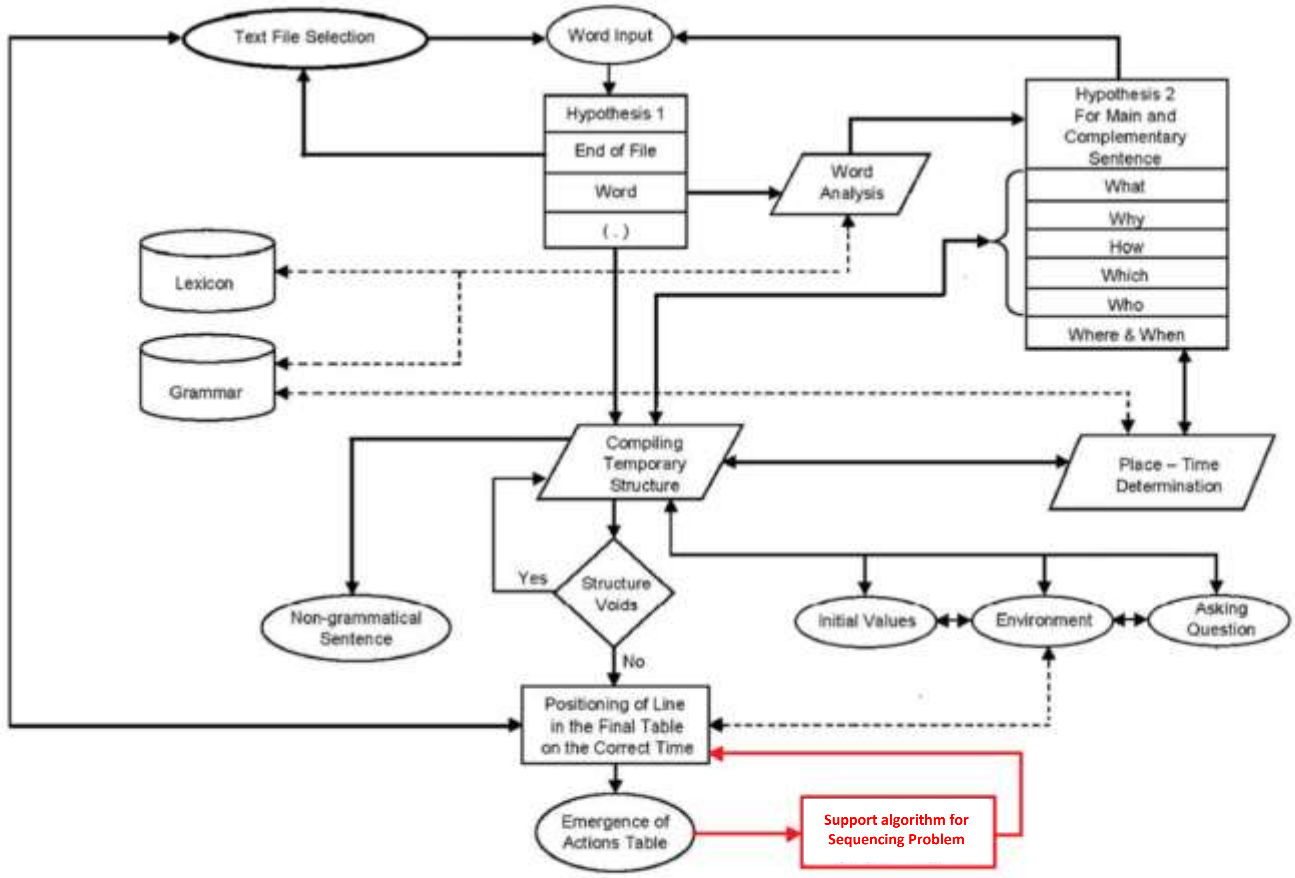

Fig. 3: The block of new algorithm as placed in the basic algorithm, with red color

In this case, the assistant receives sentences in the second person since the command giver addresses the recipient directly. Here, the assistant does not have to do anything beyond prioritizing the sentences. Additionally, we infer that in this case, the imperative is used.

4.1.3 The Assistant Receives Sentences from the Human Recipient

Here, the human recipient in need of support monologues with the assistant as the listener. The assistant ultimately receives the sentences in the first person. Again, it must convert these sentences into the second person to address the recipient correctly. Thus, if the recipient's statement is: "I need to complete this Task," the transfer from the assistant to the recipient will be: "You need to complete this Task," as in the first case. Here, too, the verb must change because, in the Greek language, verbs have different endings for each person.

4.2 Algorithm Development

According to the specifications above, the algorithm can be designed to support humans with brains in sequencing problems.

In the algorithm design, presented in Figure 2, we will start with an "IF-THEN" statement, regarding the existence of the imperative. If the imperative is detected, then we have the second person, so it remains as it is. If the answer is negative, then we may have the first or third person. This case is covered with two consecutive "IF-THEN" statements, where the negative response leads from one to the other and ultimately results in maintaining the grammatical person, unless one of the two becomes positive, in which case the process of changing the person proceeds. The output of this process reaches the final formation of the proposal, where the process of maintaining the grammatical person also takes place. Once all proposals have turned into the second person, the chronological arrangement is done, as in the referenced work, [1]. The system can now address the user and provide tasks in the correct chronological order. The algorithm is placed at the end of its initial Figure 1, as shown in Figure 3.

5 Discussion

As mentioned earlier, an initial NLP algorithm allowed us to develop a robotic system that evolves step by step and module by module. In this work so far, in addition to the basic algorithm in Figure 1, a dynamic algorithm has been developed for learning new words and a natural language generation algorithm.

It is also noteworthy that in its initial form, the algorithm operated with a constructed-language dictionary, which, among other things, had simpler grammatical rules. This would make this system more flexible with simpler processes, but would be more challenging in communication because it would require human conversationalists with it to know the constructed language.

Therefore, another limited dictionary of the Greek natural language with its corresponding grammar was integrated into this system. These new data brought us closer to considering the system as an assistant in solving speech-related problems. An example of such use was developed in this paper, aiming for future exploration in more cases.

Considering the relation of this study to other similar ones, regarding the computerized simulation of brain condition and function, these can be roughly classified into four categories:

– Those that focus on the physical aspects of damages to facilitate brain surgery, [18], [19], [20], [21], [22].
– Those that focus on single-cell sequencing technologies (DNA, RNA), [23], [24], [25].
– Those that focus on robotic task sequencing in predefined industrial production lines, [26], [27], [28], which are not of general purpose, do not refer to brain functions, and do not include natural language processing.
– Finally, those that focus on the task-sequencing learning method, [29], [30], [31] refer to the didactic method of ordering a set of tasks from the simpler to the more complex ones.

This study of ours is not competitive or even relevant to them, since it solely and uniquely, to the best of our knowledge, focuses on the general purpose of processing time and space through natural language, potentially extended to the functional aspects of speech disorders.

6 Conclusion

This paper, has explored how a developing robotic system, based on the computational model of OMAS-III and the Hole Semantic Theory, can be proved useful as an assistant in supporting people who struggle with task prioritization. For the study, an algorithm was designed and implemented to organize tasks chronologically, capturing their correct hierarchical positions. The results in a computational setting are quite encouraging, paving the way for further brain problems in speech-related issues. Therefore, it is suggested that further research should be extended to more brain injury-related problems with speech disorders. However, the scope of the initial research is to develop a robotic system with an intelligent and innovative HRI. The integration of this system will give us additional modules in speech, thinking, and comprehension functions. So, the aim is that research into brain diseases should be timed after the completion of this system, so that the maximum potential for simulating diseases on it is available. Therefore, the immediate next priority step is the development of environmental perception and mobility. This will provide new modules that can be integrated into the initial algorithm.

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Conflict of Interest

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