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ARTICLE

A Natural Language Generation Algorithm for Greek by Using Hole Semantics and a Systemic Grammatical Formalism

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ABSTRACT

This work is about the progress of previous related work based on an experiment to improve the intelligence of robotic systems, with the aim of achieving more linguistic communication capabilities between humans and robots. In this paper, the authors attempt an algorithmic approach to natural language generation through hole semantics and by applying the OMAS-III computational model as a grammatical formalism. In the original work, a technical language is used, while in the later works, this has been replaced by a limited Greek natural language dictionary. This particular effort was made to give the evolving system the ability to ask questions, as well as the authors developed an initial dialogue system using these techniques. The results show that the use of these techniques the authors apply can give us a more sophisticated dialogue system in the future.

Keywords: Natural language processing; Natural language generation; Natural language understanding; Dialog system; Systemic grammar formalism; OMAS-III; HRI; Virtual assistant; Hole semantics

1. Introduction

The purpose of this work is to develop a computational Natural Language Generation (NLG) algorithm, for the Greek language, which will serve the human-machine communication process. An integrated HRI (Human-Robot Interaction) system [1] includes the dialogue process [2] and upgrades it to a role in relation to a Virtual Assistant [3]. In general, the need to generate sentences from an engine exists for two reasons:

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1) for instructions or information to the user,

2) for questions about ambiguities (from the system side) of incoming suggestions from the user.

The first case, is the most widely applicable case, since machines give instructions to people all the time and everywhere, whether in the form of navigators or virtual assistants in homes and services. The second case is more crucial for dialogue development, since the system itself requests the information it needs and can then use it even in the same dialogue. The information that can be sought by a machine during the dialogue process is equivalent to that which a human would seek, and a large part of it is included in the following cases:

- location information
- time information
- attribute information (color, height, distance, etc.)
- issues of ambiguity
- unknown words
- issues of grammatical structure problems, due to idioms or replacement of sentence parts by expressions or movements.

As is known, a person receives much of this information from his wider interaction with the interlocutor, as well as from his intelligence that comes from a healthy brain. Parenthetically here, it is noteworthy to mention that, in general, the mechanism by which a human brain learns, perceives, synthesizes and uses knowledge through speech is complex and much research [4] is being done in many directions in modern science. In continuing, this raises the question: What happens when it comes to a machine, which by definition lacks the intelligence of a human brain but also the ability to perceive implied expressions and movements to understand ambiguous sentences? The answer is that in the case of the machine we can define a context in which, when it does not receive from its interlocutor the required information, since it will not be able to combine it with its current knowledge, it can directly target questions to it, until the full clarification.

According to the above, an attempt is made using the theory and hole semantics [5], the computational model OMAS-III [6] and the graduate thesis "Implementation of OMAS-III as a Grammatical Formalism for Robotic Applications" [7] and its related work [8], in order to create the algorithm that will compose the queries to the human/user.

The work is structured in four chapters. In the first chapter, reference is made to the theory and semantics of holes (Hole Semantics), to OMAS-III and how the combination of all of them can work in the synthesis of natural language. In the second chapter, reference is made to the use of OMAS-III as a grammatical formalism. In the third chapter, the construction of the natural language generation algorithm is done, as examples of its use. Chapter 4 presents the conclusions and suggestions for future research.

2. Theories and models

In this chapter, a brief presentation of the theory of holes as well as the OMAS-III systemic model and their connection for the further development of the study is made.

2.1 Theory and hole semantics

Hole theory, also known as "multilevel hole theory", is an approach to linguistics that focuses on the idea that language is structured at different levels of linguistic analysis, and each level operates independently. In this theory, the holes represent the different levels of language, such as phonetic, morphological, syntactic, and semantic. Each layer operates independently, but there is cooperation between them to create the overall meaning. That is, this theory emphasizes the interaction between these levels during language processing. Thus, by understanding the structure and function of each level, we can analyze how language is created and interpreted. So we can say that this approach helps to understand language as a complex system with various levels that interact, while at the same time maintaining their own autonomy. Hole semantics [9,10] is a framework that defines underdefined representations in arbitrary object languages [11]. Hole semantics constructs types of an object language① (such as FOL② [12,13] or DRT③ [14]) with holes, into which other types can be attached. Each hole with a type (named by its label) and a connection is acceptable if it respects certain constraints.

2.2 OMAS-III

The Organizational Method of Analyzing Systems (OMAS) [6] is a diagrammatic technique of systems analysis and belongs to the category of general description techniques. The diagrammatic techniques of systems analysis were developed as tools of systemic thinking and visualization, providing a more complete and flexible way of describing the relevant concepts for each foreseeable field of application, which emphasizes the supervisory representation with the use of diagrams. OMAS-III is a designed process to achieve the best possible determination of the organization (structure and function/behavior) of an object or phenomenon (system), according to the application of basic organizational rules, adapted to specific conditions. OMAS belongs to the family of SADT④ and IDEFx techniques [15,16], being their design evolution. OMAS-III is the third improved version of the original method. A complete understanding of a system through this particular method requires answers to the unique seven fundamental questions concerning it:

- Why does it exist and work?
- What results and conclusions does it give?
- How much means (resources) does it need?
- How does it work?
- Who monitors or guides its operation?
- Where does it work?
- When does it work?

Understanding the system leads to its complete description or conversely, its complete description leads to the understanding of its structure (the structure of a whole) and its organization and operation (the arrangement concerning the relationships between its entities). These seven questions ("journalistic questions") constitute the basic assumption of a system, while the basic description of the system is made with the help of notation, implementing this assumption.

2.3 Connection of OMAS-III with hole semantic

According to the paper "Implementation of OMAS-III as a Grammatical Formalism for Robotic Applications" [7], in a minimalist language the word order should be SVO (subject-verb-object) and AN. "AN" means that words qualifying a noun (adjectives or adverbs), as well as its complements, should precede (the noun). In general, all words that qualify or complement any word, including relative noun clauses, must precede the main word. However, the Greek definite article/pronoun "TO" as well as the Greek indicative "AYTO" can be used as relative pronouns to introduce a relative clause after the verb. The reason why we have to follow the SVO and AN structure is that otherwise the language will not be minimalistic. The SVO structure is recommended for use in this language, but requires some indication to distinguish the subject from the object. Every language syntax is based on the concept "the first is the second", or "the first has the second", that is, the second word is the property of the first. Therefore, when we say "task easy", it should mean "task is easy". So we use the minimal meaning, without the need for conjunctions or articles. If we say "easy task", based on the same principle it should mean "this easy thing is a task", but now this information is not necessary. Thus, we understand "that easy thing which is a work" and more simply "an easy work".

3. OMAS as grammatical formalism

In this chapter, we will see how OMAS-III implements a grammatical formalism, so that the computer can understand sentences that arrive at the system.

① Object language is a language that is the object of study in various fields, such as logic, linguistics, mathematics, and theoretical computer science.

② FOL (First-order logic): Refers to logic in which the predicate of a sentence or statement can refer to only one subject. It is also known as first-order predicate calculus or first-order functional calculus.

③ In formal linguistics, Discourse Representation Theory (DRT) is a framework for investigating meaning under a formal semantics approach.

④ https://en.wikipedia.org/wiki/Structured_Analysis_and_Design_Technique

The following sections briefly present the study and application made in the work "Implementation of OMAS-III as a Grammatical Formalism for Robotic Applications" [7]. The flow diagram of the whole system is shown in **Figure 1**. The heart of the grammar formalism is in the box titled "Hypothesis 2", in the upper right of the diagram.

3.1 The grammatical formalism

In order to understand the OMAS-III model as a formalism tool, it is necessary for the system to answer the seven key questions, also known as journalist questions. The questions answer:

- the causality of the system (Why?);
- to the result including feedback (What?);
- in the introduction of included feedback (Which?);
- in the operating regulation conditions (How?);
- to those who oversee and guide operations (Who?);
- to the spatial aspects of functionality (Where?) and finally;
- on the temporal aspects of functionality (When?).

By answering all seven questions, our system receives all the information given to it. So, its ultimate goal is to get all the answers and if it can't do it in its "brain", then he externalizes its questions to get answers and understand the situation it is in, with the result that its intelligence also raises. More specifically:

- The question "Why" contains causal and explanatory factors (because, to). They are subordinate clauses and their answer is a supplementary clause with an explanation. It should be noted that it is not always given as a question, because knowledge is not required from the robotic system, as the robot only needs to recognize and accept it when it is given.
- The question "What" is recognized as an output of the system, and the answer is the verb used in the sentence where it is executed or was executed or will be executed, provided that the robot has detected the verb of the in-

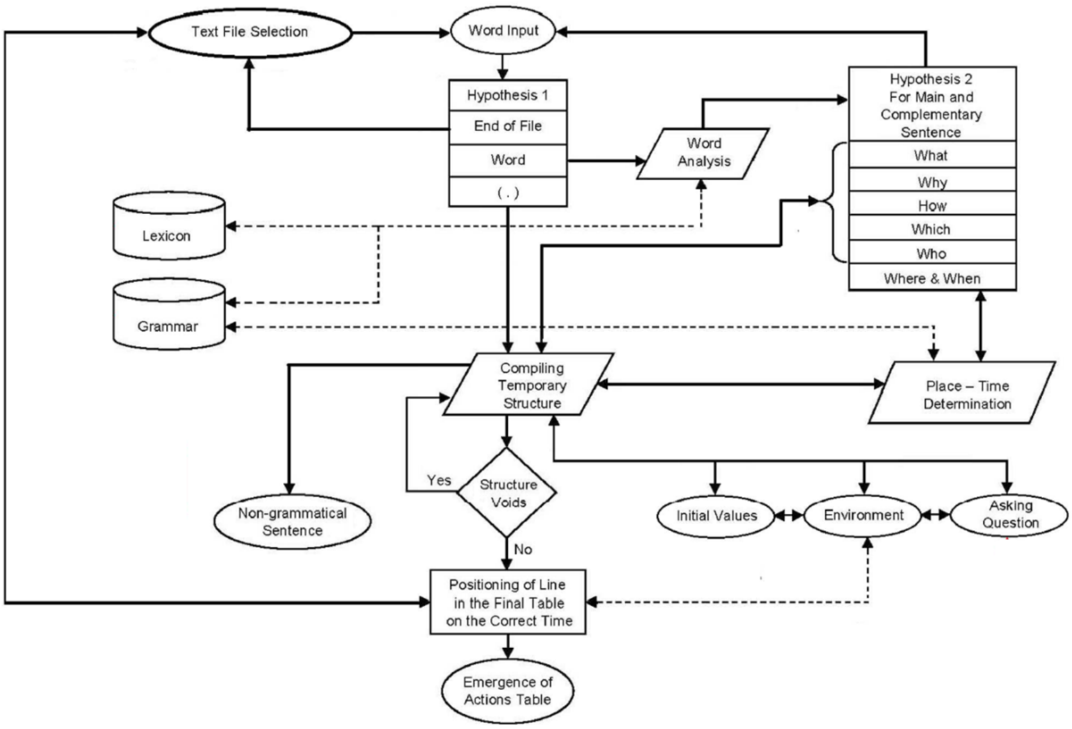

Figure 1. Basic algorithm.

Source: [8], after adaptation.

coming sentence. The purpose of the "What" question is to give the machine the ability to strip the words of the extras it may have received within the sentence and thus detect or not the verb there. If the verb does not locate it, it mainly finds the subjects or objects in the sentence and then asks what action it should do or what it is supposed to do.

- The question "Which/How much" contains all quantifiers and generally the objects of the sentence (adverbs are excluded). They are semantically placed in this position even though they do not indicate quantity, even though they are looking for what the verb should have.
- With the question "How", the action that will be used in the verb is given, with the help of modal adverbs, participles and general determinations that indicate manner.
- In the question "Who" the answer is the subject, provided the verb and object are clear in the sentence. In some cases the subject is omitted, as it may be embedded within the verb or implied. But if none of these cases applies, then the engine asks the question "Who". We usually create databases for cases like object recognition and hold the point in space and time it is meant to be found.
- When the question "Where" is asked and the place is not specified, then the robot will take for granted the current location, as it may have been defined in a previous sentence or a subsequent one of the current text. There is a chance that the machine perceives that it is a static point, with the result that the beginning and the end are identical. However, if the starting point is not given, then the robot will take as its location the previous location it was in the earlier sentence. If we don't give points or movement but ask it to be placed where someone else is, then if it recognizes someone, it takes that information and acts accordingly. It goes without saying that when the location is required but not given, the robot should not determine and ask.
- When "When" is asked, the time and moment when an action will take place is sought. Its most general form is indicated by the verb tenses and time determiners. This form is most often presented for the extended present, future and past. Along with the use of time, day and generally specific timing, it makes it easier to identify on the machine. By integrating a Real Time Clock (RTC) into a robotic system and at the same time with time management software, the machine would also experience the moments virtually. Except it would require more absolute time values than are given. For current needs, the time control given is predefined. If not declared by the data, then the robot approximates the time from the verb.
- Finally, there is the question "Why". In this particular case the machine will not have the mental capacity to give an answer, so it will not return the question again if it is not satisfied. Along with "Why" go the causal and explanatory words "because" and "to", with "to" having the role of purpose in language, but all three words are presented in subordinate clauses, where they will carry out the process retrospective.

In general, OMAS-III is a tool where the system thinks and visualizes, comprehensively, descriptions of concepts for predictable applications. It is the basic framework for building applications where robots are able to ask questions and provide information based on their existing and acquired knowledge.

3.2 Semantic grammars

Semantic grammars [17] consist of three steps:

- The primary is the semantics of the sentence accepted by the machine. Through a tree diagram, called a semantic interpreter, it derives the interpretation. It also contains conceptual dependency, where it represents language-independent concepts.
- The second step is the grammar features that have the pattern of frames and the act of unification to handle the semantic information.

The above two steps introduce artificial intelligence that makes the robot-machine capable of asking questions beyond statically recording language structures and relationships. The last step is constraint-based grammars [18], which contain hundreds of rules and are applied to multiple languages with a systematic success rate of over 99%.

3.3 Software design

The logic of the software design consisted of computational functions, where it would be permissible for the system to manage the data it would receive in the form of propositions, to perform detailed questions where necessary, and finally to expose lists of actions, ordered in time order, containing all details of who, where, when and how. All words found in the sentences are parsed and the results are stored in a temporary table. Nevertheless, the sentences that show deficiencies in objects and subjects, through a mechanism of clarification, are separated into necessary data. Clarifications are sought in already existing data of the text, however, in case no answer is found, then queries are executed. A necessary condition is the use of initial values, where they occupy the position of grammatical elements. By going back and completing the sentences, the temporary table is finalized, and all the data are transferred in time order to the time list of actions. The ultimate goal is for our system to offer the appropriate action that is requested and at the same time to determine in time the moment of its performance. The choice is made for the present, past and future tenses. In addition, in case the sentence consists of more specific temporal data, the action will be further characterized. The incoming data is passed through a six-option filter that sorts and characterizes it into words, according to the question it has to answer. It should be noted that if it is related to an explanation determination or is a supplementary proposal, then a corresponding process is activated in order to accept the new proposal. In this case, if the sentence does not contain all the features of grammar, based on the syntax of the language, then an analogous message is externalized to the outside world. On the other hand, if there are deficiencies in the structure of the sentence, then there is a two-way communication with the outside world. This has the effect of creating a temporary one-dimensional array, where the data of a sentence are expanded to construct a data line (i.e. a standardization of input data), with the ultimate goal of organizing the system to cope with what is asked of it. If there are any misses, then a temporary structure process takes place to search for data until the answer is negative, to place the line into a 2D output array, and finally give it to the outside world.

3.4 Complications

Through experiments and processing, some malfunctions appeared. The first was the involvement in endless processes, where a review was made of sentences that presented syntactic errors, and where it was possible to correct them under various conditions. The second difficulty was system-wide problems that could not be completely fixed. In general, the types of problems presented are either morphological (handling complex words), syntactic (determining the part of speech of words) or semantic, because the dictionary used each time is considered finite.

4. The NLG algorithm for Greek

In this chapter, we will see the algorithms based on which Natural Language Generation is done. In many modern methods [19], it is proposed that this process be carried out using neural networks through known techniques and their variants. In our developing system, the process of natural language generation is achieved by creating simple algorithms based on Greek grammar. These algorithms are in flowchart form. First, however, we will show how the perception and recognition of a word takes place, given a natural Greek language dictionary, as presented in the paper titled "Systemic and Whole Semantics in Human-Machine Language Interfaces" [20].

4.1 Creating word perception in the system

In a previous referenced work [7], an artificial language SostiMatiko was used. The concrete language has a great advantage in relation to the morphology of the words. The root in each is grammatically invariant, for any part of speech and for any tense. Thus, a specific ending that is the same for all words determines whether we have a verb, an adverb, a noun or an adjective, singular or plural, subjunctive or imperative, and so on. In the case of natural language, however, this does not happen, at least for most of the cases. So the Greek word "ελα" for example (**Figure 2**: come_IMPERATIVE), is a verb in imperative and becomes "έρθω" in future (**Figure 2**: I will come), "έρχομαι" in present continue (**Figure 2**: to come), "ήρθα" in past (**Figure 2**: I came), etc. In English language the corresponding single word is "come". In the case of the Greek word, it becomes clear that in natural language the process becomes more difficult and the limited dictionary is imposed, since we need to have more information for the development of a source root. For the above reason, in the database each root that gives a series of words, changing only the endings, should have its own position. Any group of such roots that show the same root meaning should be linked to that meaning (**Figure 2:** Linking meaning-root-endings to form words). This way we find its tense and grammatical position and can change it accordingly to return a sentence. That is, if a command comes: "έλα εδώ τώρα" which means in English "come here now", the answer should be given: "έρχομαι εκεί τώρα" meaning "I come there now". Although this whole process goes beyond the scope of this work, let's make a small and simple report about the mechanism during the formation of words, in such a system. In the scheme of **Figure 2:** Linking concept-roots-ends to create words, we essentially observe three levels. Above is the general meaning of the word. Then we have three roots (ελ-, -ρθ-, ερχ-) that belong to this concept. For the root "-ρθ-" we have the development of two new roots, based on a phoneme "**ε-**" or "η-" placed before it. At the third level, there are all the endings that are attached to the roots to form a final word that defines a verb at a time to some person or persons, and so on.

This does not stop here, because the same roots, or others connected with the same meaning, give us adverbs and other parts of speech.

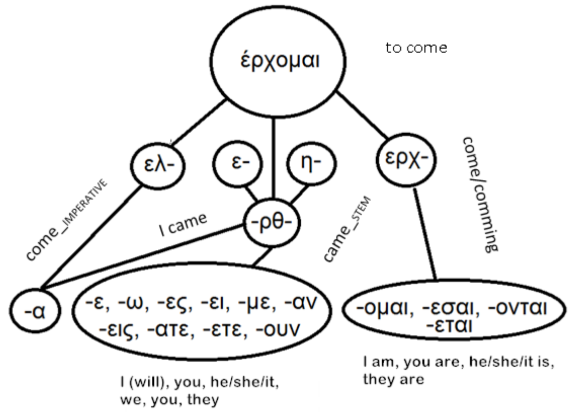

Figure 2. Linking meaning-root-endings to form words.

4.2 Word recognition algorithm

The word recognition algorithm is shown in **Figure 3**. The word recognition algorithm is described as follows:

- Each word enters the beginning of the algorithm.
- An object is initially created in which the grammatical characteristics of the word will be registered. They are registered in two variables, the length of the word and the length of the base with the roots, which is a dynamic element and can change during the operation of the system, learning new words [20].
- It looks to find which roots are shorter in length than the word. If it is not found, then the process stops and the sentence is not correct.
- If roots are found that are shorter than the length of the word, then a root that is contained in the word is searched for among them. If not found, then it will go back two steps and be rejected. If it is found, then the attributes of the word will be written to the object that was originally created, and the process will stop.

Based on the algorithm above, we check and identify all the words one by one. As long as all the words in the sentence are correct, their corresponding objects have been created. Thus, we have a com-

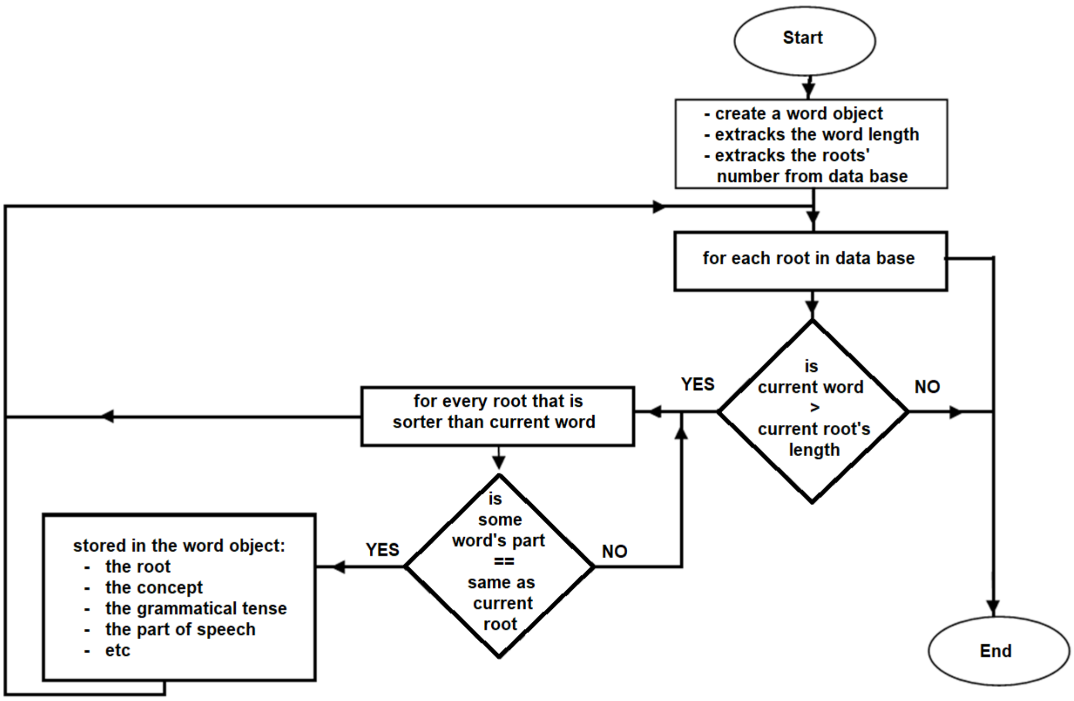

Figure 3. Word recognition algorithm.

plete mapping of the sentence, both morphologically and conceptually.

4.3 NLG algorithm for Greek

The creation of speech with a composition of natural Greek language is done after determining some basic elements. For example, the system must know all the grammatical features that will characterize the sentence, such as its person, verb and tense, as well as the object. The attributes combined with the predefined concept create the extracted sentence. Because it's easier to understand this with a fairly simple example, we'll use the queries generated by the system when it detects gaps in a sentence. If we only have the sentence "Πήγαινε και περίμενε", which means "Go and wait", then we detect two points of ambiguity. While the proposition is correct, the system needs to know where and when. The system has detected these two gaps and needs to ask questions. What else does it know? It knows that it has been given an order, i.e. imperative in the present tense. It begins to compose the questions. Since the second person becomes first, the imperative will become passive. So the meaning of "πάω" ("go" in English) from the verb form "Πήγαινε" (imperative of "go" in English) will become "πηγαίνω" ("I'm going", in English). The questions of where and when will come in front, and will be followed by "να" ("to" in English), because it is something I will do. Thus arise the questions "Πού να πάω;" ("Where should I go?" in English) and "Πότε να πάω;" ("When should I go?" in English).

This is exactly what is described in the algorithm that follows in **Figure 4** and is considered basic for natural language generation in this work.

In the case where there is no imperative, then there is no change of person and there is no addition of "NA" (to). Of course, if the word "θA" (will) exists, then it will remain. Such examples are the sentences: "Ο Α περιμένει" (A is waiting) and "Ο Β θα πάει" (B will go), which lead to the questions: "Πού περιμένει;" (Where is he waiting?) and "Πού θα πάει;" (Where will he go?) respectively.

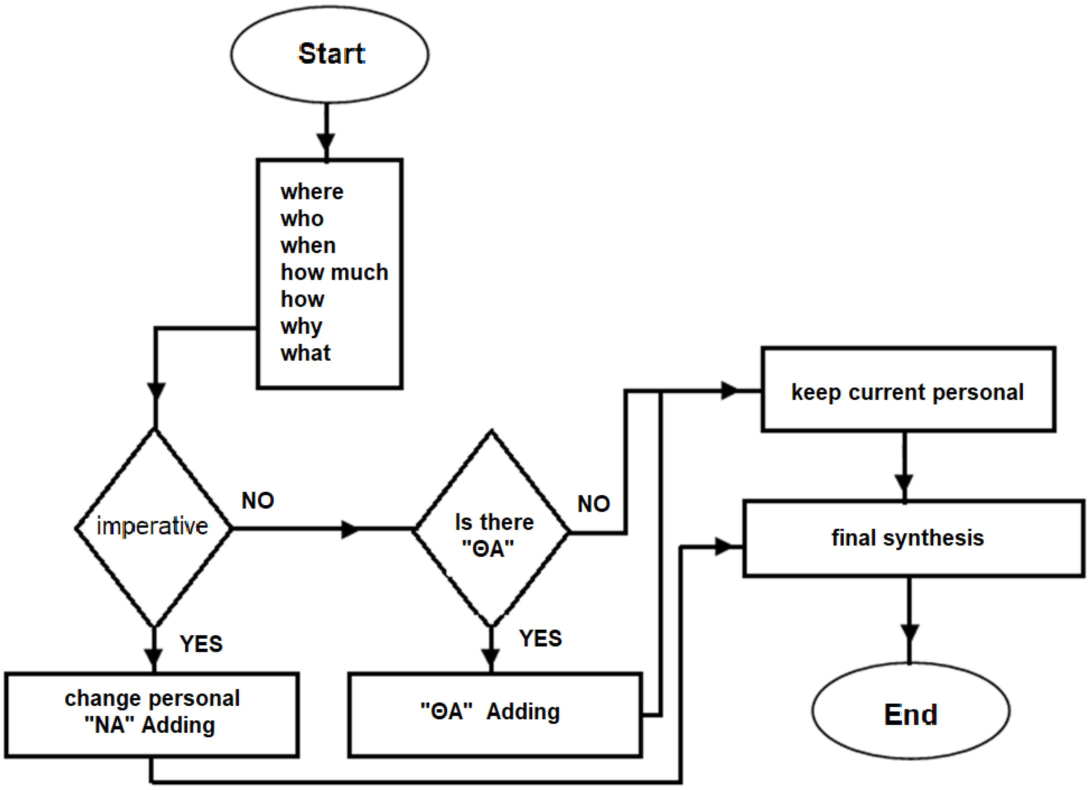

Figure 4. Basic NLG algorithm for Greek.

5. Conclusions

The following conclusions were drawn from this study:

- OMAS-III as a grammatical formalism can semantically and morphologically describe a sentence, which has been described again in the referenced work we used. In addition, with the same flexibility it is possible to compose a sentence that helps human-machine interaction through dialogue.
- This method of formalism enables us to easily intervene and add algorithms, enriching the already existing study system.

In all the studies so far on the specific techniques of OMAS-III and hole semantics, it seems that our developing system can easily accept upgrades by adding, relating or upgrading modules, such as speech synthesis, or understanding or learning a new word in the form of dialogue, etc. For this reason, we can simulate this system with various diseases of the brain, where missing a module can mean some encephalopathy. So, it is proposed as a topic of further study, the study of patients (with speech disorders), by studying problems that we will create in the OMAS-III formalism system, as it was examined in the referenced work and in the present work.

Author Contributions

All authors contributed equally to this work.

Conflict of Interest

The authors declare no conflict of interest.

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