# A Knowledge-Based Conversation System for Robots and Smart Assistants

Lucrezia Grassi*, Carmine Tommaso Recchiuto† and Antonio Sgorbissa‡
*Laboratorium - DIBRIS, University of Genoa*
Genoa, Italy
Email: *lucrezia.grassi@edu.unige.it, †carmine.recchiuto@dibris.unige.it, ‡antonio.sgorbissa@unige.it

***Abstract*—The main objective of this work is to enhance the capabilities of a knowledge-driven conversational system, making them more natural and pleasant. Exploiting several Natural Language Processing (NLP) techniques, a set of algorithms has been developed to improve the quality of the conversation and expand the knowledge base in run-time adding new concepts recognized in the user sentence. Moreover, a mechanism to validate the newly added concepts has been developed.**

***Index Terms*—Human-Robot Interaction, Socially Assistive Robots, Knowledge-Grounded Conversation, Ontology, Natural Language Processing.**

## I. Introduction

This work is carried out in the ambit of the CARESSES project: a project with the aim of designing Socially Assistive Robots that are culturally competent. This project exploits the humanoid robot Pepper as main robotic platform to interact with the users.

In the last phase of the development of the CARESSES project, the software architecture has been purposely revised to allow for a Cloud-based implementation [1]: the instructions to achieve a culturally competent behaviour are received from the Cloud. Such Cloud services are not only usable by Pepper: cultural competent behaviour is virtually accessible by any smart device which is equipped with a network connection, and has the onboard functionalities to implement the instructions it receives [2].

All assistive robots and chatbots, including the ones exploiting the CARESSES-Cloud services, still have many limitations. Some of the most common limitations are: (i) failing to answer, (ii) not understanding the local language of the user, (iii) not giving the proper answer if there is some spelling mistake or some slang, (iv) having a limited knowledge, which can result in a repetitive conversation, and (v) not being coherent when answering to what the user says [3].

As regards (iv), a desirable feature to improve the overall conversational capabilities of the system is a knowledge-base that can be updated in run-time. However, it is decisive to check the information that the system acquires, to ensure that they are reliable and that the responses do not become inappropriate.

Concerning (v), it can happen that during the conversation the agent provides answers that have nothing to do with what the user says. One of the main reasons may reside in the efficiency of the algorithm responsible for the choice of the conversation topic based on the user's sentence: if the algorithm is not capable to correctly understand the context, the agent's reply will not be appropriate even if the system had the knowledge to answer consistently.

The CARESSES system, takes its cue from this analysis, overcoming some of the aforementioned limitations by adopting an Ontology-based, knowledge-driven approach, which allows for talking about different topics, with the main aim of chit-chatting with the user about general talking points, but also being possibly customized for specific application. (i.e., a particular disease). Such conversational system may be used daily, to talk about general conversation topics and perform some activities, with the final aim of relieving the sense of loneliness.

This paper focuses on the work carried out for overcoming limitations (iv) and (v) of knowledge-driven conversational system, consisting in developing a set of algorithms to enhance the verbal capabilities of the CARESSES system. In particular, the work has been focused on the following tasks:

1) The recognition of new concepts in the user's sentence, exploiting the Dialogflow Web service [4];
2) The addition of the recognized concepts to the knowledge-base of the system at run-time, with the possibility of choosing among four insertion methods: this feature allows to overcome the aforementioned limitation (iv);
3) The validation of each new concept, before it becomes an integral part of future conversations, based on the opinions of other users;
4) The development of a Dialogue Algorithm that aims at keeping the coherence during the conversation, by properly selecting the topics to be addressed depending on the user's input: this feature is meant to work out the aforementioned limitation (v);
5) The integration in the system of the Small Talk functionality to answer to the most popular requests/statements of the users such as "Hello", "How are you?", "Good morning", etc., making the system more friendly.

Most of these tasks exploit Natural Language Processing (NLP) Python libraries and/or NLP-based web services.

All the developed algorithms have been fully integrated into the CARESSES *dialogue framework*, accessible by any device able to connect to the CARESSES Cloud.

## II. Methodology

This section describes more in detail the implemented functionalities.

### A. Recognition of Relevant Concepts

As already mentioned in Section I, a limitation of many systems is that, after a while, the conversation topics are repeated and the dialogue becomes boring. To overcome this limitation, it is important to be able to expand in run-time the knowledge base with new concepts mentioned by the user. For this reason, a mechanism to recognize relevant concepts mentioned by the user during the conversation is fundamental.

For this purpose, the Dialogflow web service has been exploited. This web service offers a wide variety of pre-trained Agents able to manage the most common functionalities for which it is used, such as reminders, weather forecasts, alarm, etc., however, if it is used for unprecedented purposes, as in our case, the Agent needs to be trained from scratch.

To recognize meaningful concepts, the sentence is sent both to the pre-trained Dialogflow Agent and to Cloud Natural Language: another Google Web service, performing the basic NLP operations [5]. Dialogflow returns a response for each piece of the sentence split by "and". Cloud Natural Language takes the whole sentence and returns the Entities recognized and their associated Entity Type.

The "best concept" is chosen based on the priorities assigned to Entity Types: this means that the response of Dialogflow containing the Entity with the Entity Type with the highest priority is chosen as best concept. Eventually, such concept is lemmatized, before proceeding with its insertion in the Ontology.

### B. Insertion of the New Concepts in the Ontology

Once a concept has been extracted with the methodology described in Section II-A, it is essential to develop an efficient strategy to add this concept to the knowledge base. In the specific context of the CARESSES framework, an insertion routine that allows the run-time insertion of new concepts into the Ontology has been developed. This step is fundamental as it allows us to expand the Ontology, overcoming limitation (iv) mentioned in Section I: the system will be able to talk about more topics after each interaction with a user.

The insertion routine calls one of the four developed insertion methods: (i) a Brute Force Method, (ii) a method that exploits the Entity Type of the extracted concept, (iii) a method based on the definitions of the concept given by the user, and (iv) a method based on the category of a sentence regarding that concept (asked to the user).

### C. Validation of Newly Added Concepts

Thanks to the insertion mechanism described in the previous Section, every user has the right to add new concepts to the knowledge base.

The addition of a new concept implies the creation of a new class along with its associated individual with some associated properties, so that it can become an integral part of future conversations with other users. It is important to mention that, at a later stage, in case the system on the Cloud will be shared by multiple devices/robots, all newly inserted concepts will be controlled before becoming part of the conversation: this prior "filtering" operation will be performed to avoid the insertion of inconvenient concepts or inconvenient additional information.

For now, this *moderation* has not yet been implemented, however, a *peer review* mechanism to validate the belonging of a concept to a class has been developed. When the system will be fully operational, both validation mechanisms (moderation + peer-review validation) will be exploited.

The correct positioning of new concepts in the Ontology is fundamental, as it will influence the coherence and the pleasantness of the conversation, hence, it is fundamental to have a mechanism that allows to verify if the newly added concepts have been placed in the correct position.

### D. Modified Dialogue Algorithm

In the context of the CARESSES project, an algorithm exclusively based on the detection of keywords has been developed. However, this approach, although allowing for implementing a dynamic verbal interaction, has some huge weaknesses.

The first issue is that it may happen that the user is not talking about a certain topic however, a keyword in the sentence is enough to trigger the *topic jump*.

The second issue related to the behaviour of this algorithm arises when no keywords are found and there is nothing else to say about the current conversation topic: in this case, as already mentioned, the algorithm *jumps* to a random topic.

For these reasons, the Dialogue Algorithm has been recently modified to improve the overall quality of the dialogue by making the choice of the conversation topic more coherent with the user's utterance, hence reducing incoherent *topic jumps* during the conversation.

For this purpose, such algorithm not only exploits the keywords, but it also takes into account the category of the user's sentence, provided by Google Cloud Natural Language. To exploit this information, a mapping between Ontology topics and the categories recognized by Google has been previously performed: in this way we have the chance to find which is the topic that matches best (i.e., has more categories in common) with the classified user's sentence. This information has also been used for the last insertion method (i.e. the one based on the category of the sentence), mentioned in Section II-B.

### E. Small Talk Functionality

The Built-in Small Talk functionality offered by Dialogflow has been used to improve the user experience by managing casual conversation. This functionality has been enabled for our customed Agent, without adding new Intents.

Let's assume that the user says a simple sentence such as "hello": the CARESSES system could answer appropriately only if the Ontology contained a topic with associated keyword "*hello*". This would imply having classes in the Ontology dedicated to the Small Talk. Such approach would imply two problems: (i) from an ontological point of view, this strategy would be improper, (ii) the management of the Small Talk through the Ontology is cumbersome and poorly flowing.

To overcome these problems, the Small Talk feature offered by Dialogflow has been exploited: such feature is meant to provide responses to casual conversation and it can greatly improve the end-user experience by answering common questions outside the scope of the Agent.

## III. Experiments

To validate the features that this work brought to the system, four experiments have been carried out.

The first experiment aims at testing the accuracy of the Dialogflow agent, trained to recognize concepts from the user's sentence. The results have shown that, in most cases, the agent is able to recognize at least one relevant concept per sentence. The recognized concepts are then added to the knowledge base of the system, exploiting one of the developed insertion methods, mentioned in Section II-B.

The second experiment is meant to assess the efficiency of the insertion methods: the methods are compared based on the number of steps required to insert the concept in the correct place of the CARESSES knowledge base. The Wilcoxon signed-rank test has been used to determine whether there is a significant difference between the methods.

Among other results, this experiment confirmed that, when the concept to be inserted has an Entity Type that has been previously mapped to an Ontology class, the best insertion method is the one that exploits this information to find the most appropriate insertion point.

The third experiment is intended to evaluate the performances of the system after the addition of many new concepts in the CARESSES Ontology. It is important to make sure that the response time of the system does not significantly increase as the knowledge base is expanded.

The experiment showed that, exploiting the developed *Dialogue Algorithm*, the average response time does not significantly increase after the addition of thousands of new concepts.

The last experiment has the purpose of comparing different Artificial Conversational Agents: (i) the system exploiting the basic Dialogue Algorithm developed in CARESSES, (ii) the system exploiting the expanded Dialogue Algorithm described in Section II-D, (iii) a version of the system randomly jumping from one conversation topic to another, (iv) a human pretending to be a chatbot, and (v) Replika: one of the most famous chatbots worldwide.

The numerous participants had to interact with one of the systems for 20 exchanges, then they had to fill in a questionnaire composed of two sections. The first section of the questionnaire required to evaluate the Coherence of each reply of the chatbot, for a total of 20 replies, in a 7-point Likert scale, while the second part consisted of the SASSI questionnaire. The published version of the SASSI is composed of 34 items distributed across six scales: Accuracy, Likeability, Cognitive Demand, Habitability, and Speed.

The results of this experiment have shown that the modifications introduced in the Dialogue Algorithm made the system significantly more coherent, more accurate, more likeable, and less annoying.

When comparing the system exploiting the modified dialogue algorithm with Replika, it turned out to have a similar Coherence, Likeability, Cognitive Demand, and Annoyance. However, the improved CARESSES system resulted to have a significantly higher Accuracy and Habitability with respect to Replika.

Although further tests have to be carried on, the tests that have been performed provide some insights on the good capacity of the system to implement an engaging, coherent and responsive verbal interaction (overcoming limitation (iv), mentioned in Section I), and recognize, and eventually acquire, new concepts efficiently (overcoming limitation (v), mentioned in Section I).

## References


[1] C. T. Recchiuto, and A. Sgorbissa, "A Feasibility Study of Culture-Aware Cloud Services for Conversational Robots," IEEE Robotics and Automation Letters, vol. 5, no. 4, pp. 6559–6566, 2020.

[2] C. T. Recchiuto, L Gava, L. Grassi, A. Grillo, M. Lagomarsino, D. Lanza, Z. Liu, C. Papadopoulos, I. Papadopoulos, A. Scalmato, and A. Sgorbissa, "Cloud Services for Culture Aware Conversation: Socially Assistive Robots and Virtual Assistants," UR 2020-International Conference on Ubiquitous Robots, 2020.

[3] H. Raval, "Limitations of Existing Chatbot with Analytical Survey to Enhance the Functionality Using Emerging Technology," International Journal of Research and Analytical Reviews (IJRAR), vol. 7, no. 2, 2020.

[4] Dialogflow Documentation, https://cloud.google.com/dialogflow/docs, 2020

[5] Cloud Natural Language API Documentation, https://cloud.google.com/natural-language/docs, 2020