HomeNL: Homecare Assistance in Natural Language. An Intelligent Conversational Agent for Hypertensive Patients Management.

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Abstract. The prospective home-care management will probably offer intelligent conversational assistants for supporting patients at home through natural language interfaces. Homecare assistance in natural language, HomeNL, is a proof-of-concept dialogue system for the management of patients with hypertension. It follows up a conversation with a patient in which the patient is able to take the initiative. HomeNL processes natural language, makes an internal representation of the patients' contributions, interprets sentences by reasoning about their meaning on the basis of a medical-knowledge representation and responds appropriately. HomeNL's aim is to provide a laboratory for studying natural language processing (NLP) and intelligent dialogues in clinical domains.

Key words: NLP, Dialogue Systems, Telemedicine, Hypertension

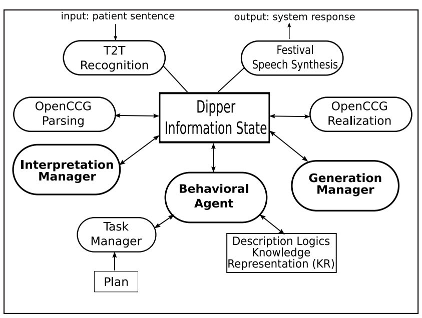
1 Introduction

A range of approaches for modeling Dialogue Systems (DSs) has been proposed in the literature from simple pattern-matching techniques to structured architectures. The most sophisticated approaches consider the cognitive state of the conversational agent and provide methods for modeling intelligent dialogues by enabling mixed-initiative and complex discourse phenomena [1]. Despite these advances, most of the dialogue-based interfaces implemented in the medical domain are devoted to simple approaches to dialogue management [2], offering system-driven applications that limit the variety of expressions users might use [1]. The adoption of more elaborated methods in the medical domain is an open research area [2]. Indeed, emergent prototypes have been deployed, of which the most salient is Chester, a personal medication advisor for elders [3]. Although the resulting prototypes are still far from being fully operative in real settings and building them requires complicated and costly solutions, these efforts highlighted promising lines of research in the field.

In this paper we present HomeNL a proof of concept for intelligent conversational agents in the management of hypertensive patients. Thereby, we have explored striking formalisms of computational linguistics and NLP. Moreover, we have adopted theoretical-based frameworks that simplify the programming burden. Despite being in a preliminary stage, HomeNL stores its cognitive state, understands and generates natural language, supports reasoning by accessing a logic-based knowledge representation (KR) and maintains a coherent conversation with a patient at the same time it enables mixed-initiative.

2 The Architecture

Several components were arranged into an extensible distributed multiagent architecture (Fig. 1, right): the open agent architecture (OAA). These components are in charge of a specific linguistic task. For instance, the language understanding and generation components were both modeled in the linguistic-driven formalism of multimodal-categorial grammars (MMCCG) [4]. DIPPER [5], which is the dialogue manager, follows the notion of *information state* (IS). Moreover, the KR was implemented in LISP and RACER was used as inference engine [6]. Further processing is carried out by the Interpreter, the Behavioral and the Generation agents that are part of the core of HomeNL whilst Festival was used for speech synthesis[1].



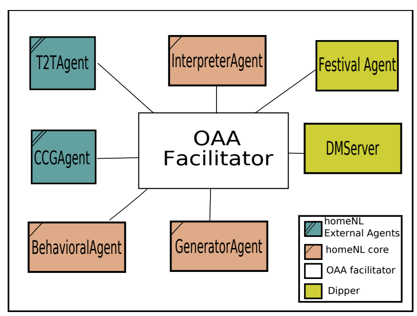


Fig. 1. Left: HomeNL architecture. Right: OAA-agents arrangement.

In its primary scope, HomeNL is concerned with the process of comprehending and using language once the words are recognized rather than the process of recognizing spoken sentences. Despite incorporating existing automatic speech recognition (ASR) inside the architecture is quite straightforward, much work remains to be done to support medical terminology in ASR's language models [3]. Therefore, the input is an Italian text sentence and the output is a coherent spoken response (Fig. 1, left). The *OpenCCG parsing* parses sentences and returns the corresponding semantic representation (SR), while the *Interpretation Manager* performs contextual interpretation. The *behavioral agent* reads the dialogue plan, goals and mandatory information before starting the dialogue. It

[1] http://www.cstr.ed.ac.uk/projects/festival/

also queries the KR and prepares the system response during the conversation. The *Generation Manager* transforms the system response into a semantic formula while *the OpenCCG realization* realizes that formula and returns the corresponding sentence in natural language. In turn, *Festival* transforms the sentence into voice.

2.1 Language Understanding and Generation

An Italian grammar was developed by using OpenCCG[2] for building MMCCG grammars. MMCCG is based on the lexicalized grammar formalism of combinatory categorial grammars (CCG), in which a grammar is defined in terms of *categories* in the *lexicon*. Categories define the part-of-the-speech of words and their relation with adjacent words in sentences. The lexicon is a complete dictionary of words that describes their lexical categories, linguistic (e.g., number, gender, etc.) and semantic features. Categories in a sentence are derived by applying combinatory rules that license the parsing and generation of several linguistic phenomena while the SR is built compositionally via unification. MMCCG has a mild context-sensitive generative power, thus it can handle a variety of constructions from a number of languages [4].

The grammar was implemented not only for parsing users' utterances but also for generating possible system responses. It is made up of a lexicon enriched with the morphology of words and a medical ontology. This ontology is used to build a SR that references ontological concepts. Nevertheless, the SR provided by OpenCCG cannot be used for reasoning [7]. The resulting grammar contains around 300 words including their inflected forms, grouped into 84 categories. These are further arranged in 65 lexical families. In spite of being a short grammar, it supports the Italian constructions commonly used by patients and doctors as collected by the Homey Hypertension Management project [8], used to either claim or inquire about health conditions, measurements, side effects, health status and habits. We are currently working on extending the CCG grammar in compliance with the Italian guideline for the management of hypertensive patients considering risk management and further constructions regarding symptoms and habits.

2.2 Description Logics Knowledge Representation

Description Logics (DLs) was selected to represent the medical knowledge [9]. It bears information about the patients' body, illness and therapy. In particular, it contains concepts related to active principles, medicines, symptoms and measurements e.g., blood pressure, weight and heartbeat. Concepts are defined as presented in Example 1, symptoms can be localized, if they affect a specific body-part, or unlocalized e.g., cough or fever. All the information about active principles and symptoms described in Table 1 has been formalized in a similar

[2] http://openccg.sourceforge.net/

fashion. Therefore, it is possible to perform inference tasks in RACER regarding the patient's side-effects and condition e.g., normal, low risk or serious.

$$
\begin{array}{ll}
\textit{TBox} & \\
\text{symptom} \equiv & (\text{local-symptom} \sqcup \text{non-local-symptom}) \\
\text{irregular-intestine} \equiv & \exists \text{affects-locally}.\, intestine \sqcap \\
 & \exists \text{has-property}.\, irregular \\
\text{calcium-antagonist} \equiv & \exists \text{produces-secondary-eff}.\, (\text{swelling-leg} \sqcup \\
 & \text{irregular-intestine} \sqcup \text{tachycardia}) \\
\ldots & \\
\multicolumn{2}{l}{\equiv \text{ equivalence } \sqcap \text{ conjunction } \sqcup \text{ disjunction } \exists \text{ existential quantifier}}
\end{array}
\tag{1}
$$

Table 1. Knowledge about drug-types, medicines and possible side-effects for the management of patients with hypertension implemented in the knowledge base.

Active Principle	Symptoms	Medicines
Aceinhibitor	cough	ramiprile, captoprile, enalaprile
Calcium-antagonist	swelling legs, irregular intestine, tachycardia	lacidipina
Diuretic	tiredness	furosemide, candesartan-hct
Betablocker	impotence	atenololo, atenololo-clortalidone, nebivololo
Alpha1bp	tachycardia	doxazosin
Alpha2ac	driesout mouth, driesout eyes, blush face, drowsy	clonidina

2.3 The Information State

The information state theory proposes a blackboard structure (i.e. the IS), a set of update rules and a set of dialogue moves to model dialogues [10]. In DIPPER the IS and the update rules are declared in the OAA-logical language, namely the interagent communication language (ICL). On the one hand, the IS keeps track of the relevant information of the discourse e.g., *cognitive state*, *goals*, *mandatory information*, *plan*, *input*, *SR*, *unsolved goals*, etc. In addition, the IS contains the information to be grounded (to be clarified) and *the common ground* with the information that has already been clarified, that is to say, the information shared by both HomeNL and the patient. On the other hand, the update rules implemented are *initialisation*, *recognise*, *parsing*, *interpreting*, *behavior*, *generating*, *realizing* and *synthesise*. The dialogue moves, also called dialogue-acts, deployed are *assertions*, *information requests* and *grounding* acts. Information requests are usually performed by HomeNL while assertions and grounding-acts are performed by both the system and the patient. Further details about HomeNL are given in [7].

3 Discussion and Future Work

Several levels of linguistic analysis (e.g., syntactic, semantics, pragmatics and discourse) were studied and implemented in HomeNL. The selection of MMCCG formalism for language understanding and generation pursued the improvement of home-care automated-dialogues by making the interaction less restrictive than those widely adopted systems that merely exploit the generative power of context free grammars (CFG). Unlike similar prototypes in health that enable mixed-initiative through extensions to CFG, like augmented-CFG [3], here we developed and evaluated a categorial grammar formalism for language understanding and generation. The understanding capability was evaluated on the basis of the concept accuracy metric [11] giving an accuracy of 91.32%, whereas the generation capability has been tested in the realization of 74 sentences, giving an accuracy of 89%. We plan to evaluate HomeNL on the basis of usability test and we expect to improve patients' satisfaction of the system in comparison with HOMEY [8], the precedent dialogue for the management of patients with hypertension.

HomeNL can be improved by integrating an ASR and by filling up the KR with electronic health records (EHR) in order to support patient-tailored and telephone-linked dialogues. Furthermore, a planning agent can be incorporated in the architecture for solving dynamically changing goals at each interaction. Exploring risk reasoning in the KR is another appealing direction for future research.

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