On the use of expectations for detecting and repairing human-machine miscommunication

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Abstract
In this paper I describe how miscommunication problems are dealt with in the spoken language system DIALOGOS. The dialogue module of the system exploits dialogic expectations in a twofold way: to model what future user utterance might be about (predictions), and to account how the user’s next utterance may be related to previous ones in the ongoing interaction (pragmatic-based expectations). The analysis starts from the hypothesis that the occurrence of miscommunication is concomitant with two pragmatic phenomena: the deviation of the user from the expected behaviour and the generation of a conversational implicature. A preliminary evaluation of a large amount of interactions between subjects and DIALOGOS shows that the system performance is enhanced by the uses of both predictions and pragmatic-based expectations.

The problem
During the last few years it has been emerging that the success of spoken language systems is greatly improved by the contextual reasoning of dialogue modules. This tenet has spread through both the speech and the dialogue communities. Dialogue systems devoted to spoken language applications are able to detect partial communication breakdowns by other system modules, and that increases the robustness of human-machine interactions by speech.

During oral interactions with computers, communication problems often arise after the occurrence of errors during the recognition phase. Sometimes these errors cannot be solved by the semantic module: the utterances containing them are interpreted by the semantic analyser, but with an information content different from the speaker’s intended meaning. Detecting such miscommunications and repairing them through initialization of appropriate repair subdialogues is essential for the interaction to be successful.

Most of the research in this area has been devoted to providing the recognition and understanding modules with information generated on the basis of the dialogue context. They predict what the next user’s utterance will probably be about: throughout this paper I will refer to them with the name "predictions". Sometimes they are passed down to the acoustic recognition level in order to decrease the huge number of lexical choices, sometimes they are used to help in deciding on multiple semantic interpretations. More often they are used during the contextual interpretation phase to accept or reject parser output.

Although predictions have proved useful, they only grasp one side of the miscommunication problem. Actually they are a means for reducing recognition errors, and their use allows the avoidance of one of the potential sources of miscommunication. However during spoken human-computer interactions, the detection of miscommunications may be outside the capabilities of the dialogue system, even though it uses predictions; on the contrary, the user is usually able to detect any speech errors. For example, in travel inquiry applications words belonging to the same class, such as proper names of place, may be highly confusable. When the dialogue prediction says that next user’s utterance is likely to be about a departure place, this does not exclude that the recognizer substitutes the actually uttered name with a phonetically similar one. Only the user is able to detect such kinds of errors. In this situation the dialogue system should identify the user’s detection of miscommunication and provide appropriate repairs.

In this paper I will argue that the dialogue module ability to detect user-initiated repairs is improved if the system is able to capture the pragmatic phenomena that accompany user’s detection of miscommunication. The paper offers an analysis of the pragmatic phenomena that occur when users detect miscommunication during task-oriented human-machine spoken dialogues. The account exploits both predictions and another notion of expectation that comes from the cognitive-based research area. This notion refers to conversants’ beliefs about the relation of future utterances with previous ones in a dialogue. A computational interpretation of this notion has been done in the model proposed by McRoy and Hirst (McRoy and Hirst 1995), where it is suggested...
that speech community predictions and cognitive based expectations are complementary notions. This paper claims that accounting for these two notions is useful for detecting and solving actual breakdowns in user-system communication. The working hypothesis is that in task-oriented dialogues miscommunication often generates conversational implicatures. I will show how they are dealt with by the dialogue module of DIALOGOS, an information inquiry spoken language system implemented by Cselt speech recognition and understanding group. By using the telephone, the system may be used to access the data base of the Italian public railway company. I will report dialogue examples and experimental data that show the effectiveness of the proposed analysis in task-oriented human-machine spoken dialogues.

The working hypothesis

The conceptual background of this approach is inspired by the Gricean principles of conversation (Grice 1967). The user modeling of the dialogue module of DIALOGOS is based on the assumption that both the system and the user are active agents of the communicative process; in particular, it is assumed that both of them observe the Cooperation Principle (CP) in order to achieve the general goal of their linguistic interchange, i.e. to access a database to get the information that the user needs.

The system predictions are modelled on the basis of the CP. At each stage of the dialogue with the user the system expects that user’s reaction conforms with the CP. At each stage of the dialogue with the user the system expects that user’s reaction conforms with the CP. At each stage of the dialogue with the user the system expects that user’s reaction conforms with the CP. At each stage of the dialogue with the user the system expects that user’s reaction conforms with the CP.

- each user turn is not over or under-informative,
- each user turn communicates user’s “true” needs (i.e. to receive train timetables from place X to place Y, if the two places have been confirmed),
- is pertinent to the focus in hand.

However, as remarked earlier, in oral human-machine dialogue the communication process may be disturbed by several factors, the most usual of ones are recognition errors. The user’s detection of breakdowns and errors of the system has precise empirical consequences: these concern both user’s behaviour and her cognitive demand on the continuation of the interaction. In particular, these empirical consequences may be summarized as follows:

- the user utterance does not match dialogue predictions;
- the user asks the system to come back to the interpretation context where miscommunication occurred;
- both the user and the system should engage in a clarification subdialogue before continuing their interaction.

Since dialogue predictions are generated by taking into account the respect of the above listed maxims, and given that the system assumes that the user continues to respect the CP, each deviation of the user’s behaviour from dialogue predictions is ideally interpreted as a signal of the potential occurrence of miscommunication.

The working hypothesis is that the occurrence of a miscommunication goes along with two pragmatic counterparts: the first one is the deviation of the user's behaviour from the dialogue predictions, the other one is the generation of a conversational implicature. The turn for being "conversational" an implicature has to be inferable on the basis of the contextual knowledge. I suggest that in order to recognize conversational implicatures, the dialogue system should embody a model of user expectations that gives insights on how to relate user correction turns to the previous (normal) turns in an ongoing dialogue.

Examples of miscommunication

Non-understanding

The kind of miscommunications that occur during oral interactions of subjects with spoken language systems is usually caused by an actual breakdown in the flow of the dialogue. The most usual miscommunications may be labelled as “misunderstanding” and “non-understanding”. The latter are usually less problematic.

| T1 S: | Automatic Railway Information System. Please speak after the tone. Please give your point of departure and your destination. |
| T2 U: | Then ... What time .. I mean from [NOISE] eight |
| T3 S: | Sorry, I did not understand. Please give your point of departure and your destination. |
| T4 U: | I want to leave from Milano in the evening. I’d like to know [NOISE] from Milano to Roma. |
| T5 S: | Do you want to travel from Milano to Roma leaving in the evening? |
| T6 U: | Exactly. Around eight p.m. |
| T7 S: | InterCity 243 leaves from Milano Centrale at 20 past 8 p.m.; it arrive at Roma Termini 6 a.m. |

Figure 1: Example of non-understanding

In the dialogue reported in Figure...
understanding occurred in the turn T2: due to environment noise, the fragmentary utterance was not understood by the recognizer and no semantic representation was sent to the dialogue module by the parser. This symptom of actual breakdown causes the system to trigger an informative speech act of non-understanding and a requestive speech act for obtaining departure and arrival place names (T3).

In non-understanding the system completely fails to interpret a user’s utterance; that may happen either because a speech recognition error occurred or because the linguistic processor was not able to interpret it, for example if the semantic content of the sentence was out of its semantic coverage. Non-understanding is usually recognized by the dialogue system as soon as it happens. Within speech understanding systems non-understanding usually gives place to second-turn repairs (Schegloff 1992). For example, in the DIALOGOS system the dialogue module realizes that a non-understanding has occurred because it fails to receive any semantic interpretation for the user’s sentence uttered immediately before. In this case it enters a repair action by informing the user that her utterance was not understood and asking her to rephrase the sentence. At present the dialogue module does not know if the non-understanding was caused by a failure of the speech recognizer (because of out-of-vocabulary words, mispronouncing, unhearings, and so on) or by a failure of the parsing module. As a consequence, the user is addressed with a generic information of non-understanding.

**Misunderstanding**

Some kinds of failures in recognition and understanding cause actual human-machine misunderstanding. Let us consider the dialogue in Figure 2. The user utterance T2 has been recognized as “Aroma” instead of “Roma” (in Italian they may be confusable). This causes a third-turn repair. In the turn T4 the user, instead of giving the departure place name, realizes that the sentence uttered in the turn T2 was not correctly recognized and she repeats the arrival city. In producing T3, the system generated a prediction about the departure city, but user’s turn T4 causes it to recover. This is done by reinterpreting T4 within the interpretation context initially generated for T2. Moreover the expectations generated in interpreting T4 are different from the ones generated for T2. In T4 the system realizes that a misunderstanding happened: it discards predictions about obtaining the departure city by refocusing the interpretation context on the possible confirmation of the arrival city.

**Identifying misunderstanding**

The example reported in Figure 2 is an actual piece of dialogue (translated into English) between a subject and the DIALOGOS system. Let us now describe how the system deals with the misunderstanding. In the turn T3 the dialogue system generates a so-called “confirmation plus initiative” speech act. This means that in a single dialogue turn the system tries to get both a confirmation of what it understood from the previous user turn, and other piece of information it needs to access the database. The selection of this speech act generates a large number of expectations. The most interesting for the present discussion are listed below. For brevity, in what follows I have considered only the predictions of statements with more informational content than simple confirmation and denial by the adverbs “yes” and “no”.

1. A statement about the name of the departure city;
2. A statement about the name of the departure city and other required parameters, such as the date and the time of departure;
3. An explicit confirmation of the arrival, and the departure city;
4. An explicit denial of the understood arrival city and a request for another arrival city;
5. An explicit denial of the understood arrival city;
6. A statement including a new arrival city plus the departure city;
7. A statement including a new arrival city;

As we can observe, the expectations from (1) to (7) may be related to predictable lexical counterparts. In other words, they may be sent to the recognition level in the form of word class predictions, in order to be used for constraining the search space of the speech recognizer.

In addition, we can observe that at the dialogue level the realization of expectations (6) and (7) implies something more than the prediction of a lexical class. The linguistic realizations of (6) and (7) have the form of affirmative statements and the illocutionary force of disconfirmations. In both cases a conversational implicature is generated. The illocutionary goal of statements realizing (6) and (7) imply a precise cognitive demand by the user. Let us again consider Figure 2. T4 realizes dialogue expectation (7): the user asks the system to reinterpret T4 in the context of T2. Notice also that

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**Figure 2:** Example of misunderstanding due to substitution

T1 S: Automatic Railway Information System. Please speak after the tone. Please give your point of departure and your destination.
T2 U: I want to go to Roma.
<T "arrival-city=ARONA">
T3 S: To Arona. What is your point of departure?
T4 U: I said that I was going to Roma.
<T "arrival-city=ROMA">
T5 S: Are you going to Roma?
the user’s beliefs about the continuation of the interaction are slightly different for (6) and (7): in the case of (6) the focus of attention of both user’s and system are still on the same speech act, i.e. the disconfirmation of the arrival city and the proposal of a departure city. On the contrary, in (7) the user expects that before requesting a new parameter the system will be able to correct its previous misunderstanding. In other words, she demands a focus restriction in order to correct the misunderstanding. An appropriate system answer in situations like (6) and (7) requires that the system be able to grasp the illocutionary force of user statements in order to redirect the dialogue strategy.

Dealing with misunderstanding

Let us consider in Figure 3 another excerpt from an interaction between DIALOGOS and a subject.

T1 S: Automatic Railway Information System. Please speak after the tone. Please give your point of departure and your destination.
T2 U: From Milano to Roma.
<departure-city=MILANO *arrival-city=ARONA>
T3 S: Do you want to travel from Milano to Arona?
T4 U: From Milano to Roma.
<departure-city=Milano arrival-city=ROMA>
T5 S: Do you want to arrive in Roma?

Figure 3: Example of repair with repetition

In the turn T3, DIALOGOS prompts the user for confirmation with a Yes/No question. At this point the system linguistic predictions concern a confirmation or a negation speech act by the user. In T4 the user produces an affirmative sentence which has the illocutionary force of a disconfirmation. By analysing a large number of interactions between users and the DIALOGOS system, we actually realized that in this application context Italian speakers very often start a repair without an explicit negation word such as “No”: on the contrary, they repeat their previous utterances louder. Notice that in Italian repetitions mostly work for confirmation (Bazzanella 1993), but in that case the intonational contour is unstressed.

As proposed above, in order to recognize the dialogic repetition of the turn T4 as a user-initiated repair, the dialogue system has to be able to take into account both the deviation of the user from the expected behaviour, and the illocutionary force of her utterance (i.e. the denial of the system interpretation of T2). This deviation is the signal of an actual misunderstanding and it is related to the presence of a conversational implicature.

The dialogue system initially interprets T4 with respect to its set of expectations. As soon as it realizes that the matched expectation realizes an implicature, it reinterprets T4 within the context of the utterance whose interpretation is now denied, i.e. the system traces back to the interpretation context of T2. The fact that T4 is now being reinterpreted in the context of T2 causes a refocusing of the dialogue context. In the present DIALOGOS version the refocusing mechanism is allowed through the maintenance of both a linguistic history and a context hierarchy (further details of this are reported in the section that describes the dialogue system).

All the examples discussed above concern third-turn repairs; however, repairs from misunderstanding may occur also in subsequent turns, as the example in Figure 4 shows.

T1 S: Automatic Railway Information System. Please speak after the tone. Tell me from where you want to leave and where you want to go.
T2 U:... leaving from Pisa at eight [NOISE] this morning [NOISE] Firen-
< *departure-city=PISA-AEROPORTO
departure-time=MORNING date=TODAY>
T3 S: From Pisa Aeroporto. Where are you going to?
T4 U: To Firenze.
<arrival-city=FIRENZE>
T5 S: From Pisa Aeroporto to Firenze?
T6 U: From Pisa ... Stazione Centrale to Firenze
<departure-city=PISA dep-station=CENTRALE
arrival-city=FIRENZE>
T7 S: From Pisa Centrale?
T8 U: Yes
<confirmation=Yes>

Figure 4: Example of misunderstanding

In this example the sentence uttered in the turn T2 was badly recognized. For the sake of simplicity, let us concentrate on what happened about the names of the departure and arrival city. Due to disturbances over the phone line, the uttered arrival city name (“Firenze”) was not decoded. Moreover the phrase ”from Pisa at eight” (in Italian, “da Pisa alle otto”) was recognized as ”Pisa Aeroporto”. The system expectations were not satisfied since the name of the arrival city was not acquired. Then the dialogue system decided to trigger a confirmation plus initiative speech act in order to obtain the missing parameter and to confirm departure. That choice resulted in the generation of T3. At this dialogue stage the set of expectations were the ones enumerated in the previous paragraph, although applied to the arrival city parameter. In T4 the user offered an arrival city. This matched the first expectation of our list. At this stage neither the user nor the system had grasped the inconsistency concerning departure. Since it had not obtained explicit confirmation for departure, the dialogue system addressed the user with the Yes/No question of turn T5. The contextual interpretation of the user utterance T6 detects the explicit confirmation of the arrival city and the misunderstanding that had occurred during the recognition of the departure city. The latter is refocused again in T7, and the user is addressed with a new Yes/No question.
Architecture of DIALOGOS

DIALOGOS is a real-time task-oriented system composed of the following modules: the acoustical frontend, the linguistic processor, the dialogue manager and the message generator, and the text-to-speech synthesizer. Its vocabulary size is about 3,500 words including 2,983 place names. The acoustical frontend and the synthesizer are connected to the telephone network through a telephone interface, while the dialogue manager is connected to a Computer Information System to obtain information about Italian Railway time-tables. The acoustical frontend performs feature extraction and acoustic-phonetic decoding. The recognition module is based on a frame synchronous Viterbi decoding, where the acoustic matching is performed by a phonetic neural network. During the recognition, it makes use of language models that are class-based bigrams trained on 30K sentences. The training data were partially derived from the trial of a previous spoken language system applied to the same domain (Baggia et al. 1994).

The linguistic processor starts from the best-decoded sequence, and performs a multi-step robust partial parsing. In this strategy, partial solutions are accepted according to the linguistic knowledge (Baggia and Rulliot 1995). At the end of the parsing stage a deep semantic representation for the user utterance is sent to the dialogue module, that will be described in the next subsection.

The dialogue module performs contextual interpretation and generates the answer which is sent to the text-to-speech synthesizer Eloquens (Quazza et al. 1993) that contains specific prosodic rules for the Italian language.

The dialogue system

The dialogue strategy of DIALOGOS has been designed both to maintain the control of the cooperative interaction and to leave the expert user the freedom to guide the interaction. Referring to the classification reported in (Smith et al. 1995), the DIALOGOS system is able to support directive, suggestive and declarative initiative modes. It only exploits the directive mode in order to deal with repetitive problems at the recognition and understanding levels. The directive mode is implemented by automatic switching to the isolated word recognition modality.

The flow of a typical interaction with the system may be divided into two main stages: the acquisition of a set of parameters, used to select a reasonably small set of objects of interest to the user, and the presentation of the information related to the retrieved objects. These two stages may lead to the combination of several subdialogues, each of them with its own purpose. The system is able to move properly through nested subdialogues thanks to the maintenance of a dialogue history which relates the focus of the current utterance to the appropriate interpretation context. A detailed discussion of the dialogue strategy is given in (Gerbino and Danieli 1993).

The system performs contextual interpretation on the basis of the model of user-system interaction discussed above. The model has been implemented using a Transition Network formalism. Each node in the network represents a state in the dialogue: associated actions are executed when the interaction comes to that state. The actions are declared in a library of functions written in C. There are specific actions for each dialogue functionality, including contextual interpretation, updating of the context hierarchy (see below), and generation of dialogue predictions and expectations. A state transition is executed when the conditions associated with the arc are satisfied. Conditions are also library functions: they check both the current state of the dialogue model and the content of the user’s utterance, in order to direct the interaction into a new coherent state. Default transitions are associated with each node.

The contextual interpretation of user utterances takes into account the linguistic history and the global and local (active) focus (Grosz 1983, Suri and McCoy 1995). Each time a user utterance has to be interpreted, all the information useful for its interpretation (specifically, its semantic content and some surface information that may be used to solve references) are stored in a cycle-structure (Baggia and Gerbino 1993). At each point of the dialogue, the linguistic history consists in the history of the previous cycle-structures. The interpretation of the utterance causes the creation of a local focus structure which is linked to the cycle-structure that has caused it (Gerbino and Danieli 1993). The focus structures are hierarchically organized in a tree (that we name ”context hierarchy”), whose root represents the global focus at the beginning of the dialogue. A new node in the tree, that is a new active focus, is created and linked in the hierarchy when the user operates a focus restriction or a focus shifting. The correct interpretation context of an utterance can be the active focus, if the utterance refers to the objects currently focused; when there is discrepancy between utterance focus and active focus, the hierarchy is climbed up for checking the semantic and pragmatic consistency between the current utterance and the previous ones. The first node where the consistency is verified is chosen as the utterance interpretation context.

Experimental Data

Recently DIALOGOS has been tested in a large field trial. Five hundred subjects of different ages and levels of education called the system from all over Italy. They had never used a computerized telephone service before. Each of them made three calls to the system. The experimental material has been transcribed and it is currently being evaluated.

Subjects called the system from their own places (80%), from public telephone booths (10%), and by mobile phones used in noise environment (such as street, underground stations, and so on). They received a single page of printed instructions which contained a brief explanation of the service capabilities.
Each subject had to plan a trip from a city A to a city B in a certain date and time: they had to find out departure and arrival times of trains that satisfy their needs. The departure and the destination were specified in the scenarios, on the contrary the subjects had the freedom to choose the date and the time of the travel.

Some features of the dialogues collected in the test and already evaluated are shown in Table 1. The total number of evaluated dialogues, the number of continuous speech utterances, the number of isolated words, and the average number of continuous speech utterances per dialogue are reported.

| No. of Dialogs | No. of Utterances | No. of Iso. Words | No. of Utterances per Dial. |
|----------------|--------------------|-------------------|-----------------------------|
| 923            | 9,124              | 442               | 9.8                         |

Table 1: Corpus

A user-system interaction was considered successful when the user received all the information she needed. In particular, the transaction success is the measure of the success of the system in providing users with the train timetables they required. A definition of transaction success and related dialogue evaluation metrics is given in (Danieli and Gerbino 1993). The rate of transaction success for the 923 evaluated dialogues is 84%. We consider this result a promising starting point for further work within the conceptual framework described in this paper.

Conclusions

This paper discusses the use of expectations for dealing with miscommunication in spoken dialogue systems. It has been suggested that the deviation of the user’s behaviour from predictions, along with the generation of a conversational implicature, are symptoms of actual miscommunication. The proposed analysis exploits two notions of expectations. The first one refers to predictions: they have been largely used by the speech community to reduce speech and semantic interpretation errors. The second expectation notion gives insights on how to relate future user utterance to previous ones. The described approach has been implemented in the dialogue module of the DIALOGOS spoken language system.

The level of appropriateness of the system’s answer when miscommunication occurs is greatly enhanced when the spoken dialogue system is able to profit from both kinds of expectation. Some experimental data support this claim. Preliminary results (based on 923 dialogues with naive users) show that the rate of transaction success of the system is 84%.

Although this analysis is only a first step towards an adequate handling of miscommunication within our automatic speech recognition system, it has been shown to be useful in improving the overall performance of the system.

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