A dialogue act based model for context updating

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Abstract

In this paper we describe a context update model that has been implemented in a dialogue manager. The model is based on the assumptions that utterances in a dialogue can be represented in terms of dialogue acts, and that they provoke several types of effects in the dialogue participant's belief state. In the paper, a step-by-step analysis of the context update during a dialogue will be provided, focusing on the belief states of the dialogue participants.

1 Introduction

In this paper we describe a context update model that has been implemented in a dialogue manager that operates within an interactive question answering system (Keizer and Bunt, 2006), making it possible to develop complex dialogue act generation mechanisms that employ the rich information provided by the beliefs in the context model.

The context update algorithm is built on Dynamic Interpretation Theory (DIT), (Bunt, 2000), in which dialogue utterances are interpreted as having intended context–changing effects that are determined by the dialogue act(s) being performed with the utterance. So, generally speaking, we follow the Information State Update approach in dialogue modelling (Traum and Larsson, 2003), with a strong emphasis on dialogue acts and a complex context model.

The context update is based on the specification of the preconditions of the dialogue acts in the DIT taxonomy, which describe the motivation and assumptions of an agent to perform the dialogue act, and on the representation of several types of effects that utterances have in the belief state of dialogue participants.

This paper is organised as follows. Section 2 presents the theoretical background. In Section 3 we describe the update model, which is then applied to an example dialogue in Section 4. A step-by-step analysis of the context update during a dialogue is provided, showing how the belief states of the dialogue agents evolve, provoking changes in the context model that have a role in the generation of utterances. Section 5 ends the paper with discussion and conclusions.

2 Theoretical background

In Dynamic Interpretation Theory (DIT) (Bunt, 2000), a dialogue is modeled as a sequence of utterances expressing sets of *dialogue acts*. These are semantic units, operating on the information states of the participants. Formally, a dialogue act in DIT consists of a *semantic content* and a *communicative function*, the latter specifying how the information state of the addressee is to be updated with the former upon understanding the corresponding utterance. Communicative functions are organised in a taxonomy[1] consisting of ten *dimensions* (Bunt, 2006): Task-Oriented acts, Auto-Feedback, Allo-Feedback, six dimensions of Interaction Management (IM), such as turn- and time-management, and Social Obligations Management (SOM). Several dialogue acts can be performed in each utterance, at most one from each dimension. Dimensions of communication are different aspects of the communication process that can be addressed independently and simultaneously by means of dialogue acts.

[1] See web page http://ls0143.uvt.nl/dit/.

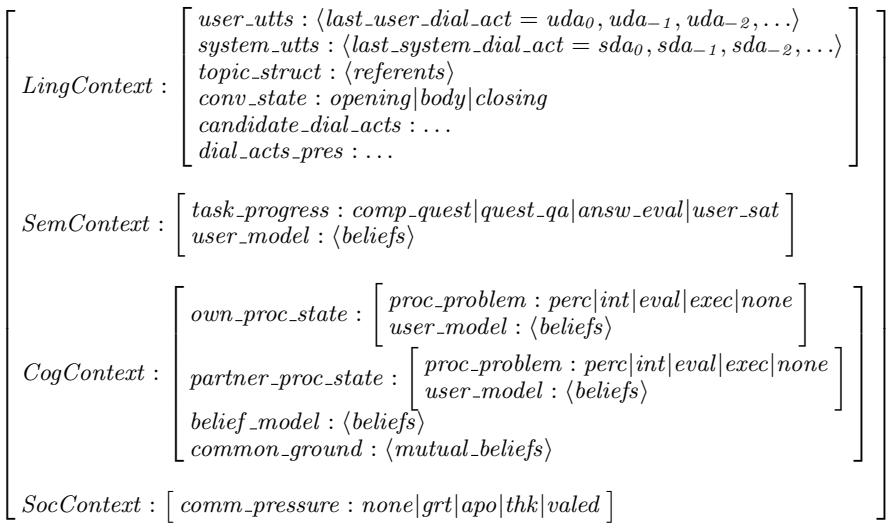

Figure 1: Feature structure representation of the context model used.

A participant's information state in DIT is called his *context model*, and contains all information considered relevant for his interpretation and generation of dialogue acts. A context model is structured into several components:

1. *Linguistic Context*: linguistic information about the utterances produced in the dialogue so far (a kind of 'extended dialogue history'); information about planned system dialogue acts (a 'dialogue future');
2. *Semantic Context*: contains current information about the task/domain, including assumptions about the dialogue partner's information;
3. *Cognitive Context*: the current processing states of both participants, expressed in terms of a level of understanding reached (see Section 3.3);
4. *Physical and Perceptual Context*: the perceptible aspects of the communication process and the task/domain;
5. *Social Context*: current communicative pressures.

In Figure 1, a feature structure representation is given of our context model. The context model is extensively described in (Keizer and Morante, 2007). Currently, information about the physical and perceptual context is not considered relevant for the types of dialogue and underlying tasks that we will consider in Section 4.

In updating the context model on the basis of dialogue acts, their preconditions form the basis for changing the system's belief model. There is a correspondence between the dimension of a dialogue act and the components of the context model it particularly operates on. For example, dialogue acts in the task/domain dimension typically provoke changes in the *Semantic Context* and SOM acts typically create or release communicative pressures as recorded in the *Social Context*. The meta-information for user utterances typically results in the recording of processing problems in the own processing state of the *Cognitive Context*. Feedback acts also provoke changes in the *Cognitive Context*, but may cause beliefs in any part of the context model to be cancelled. The system providing domain information to the user will result in a belief in the *Semantic Context* about the user now having this information, but that belief will have to be cancelled when the user then produces a negative auto-feedback act, indicating he did not hear or understand the system's utterance.

In the next section we describe the part of the update model related to updating the beliefs of dialogue participants.

3 The context update model

Regarding the context update, DIT follows the same basic idea as the information state update approach (Traum and Larsson, 2003): the context model is updated during a dialogue under the influence of the participants' utterances, depending particularly on the *dialogue acts* performed. The context update starts from an abstract representation of the utterances in terms of dialogue acts. Dialogue acts

have preconditions, which represent the motivation and assumptions required for the agent to perform a dialogue act. This approach is similar to the BDI paradigm (Allen and Perrault, 1980).

In order to explain the epistemic aspects of the context update, DIT defines mechanisms for context update, as well as several types of effects that utterances provoke in the context model. This section is devoted to present both the mechanisms and the types of effects, whereas the next section will present the analysis of a dialogue.

3.1 Mechanisms for context update

The four mechanisms for context update are creation, adoption, strengthening, and cancellation of beliefs.

Creation: Belief creation is the effect of assigning an interpretation to what has been said. When an utterance is understood by an addressee A as a dialogue act of a certain type, then if *c* is a precondition of that dialogue act, A will believe that *c* holds unless *c* contradicts with other beliefs that A entertains. If *b* is a belief of S resulting from processing a previous utterance, A will believe that *b*, unless *b* contradicts with other beliefs of A.

Adoption: The adoption mechanism specifies when a dialogue participant incorporates beliefs or goals of other dialogue participants as beliefs or goals of his own. For example, when an utterance is understood by an addressee A as an information–providing dialogue act, making the information I available to A, then if A does not hold beliefs that contradict I, A adopts this information as a belief of his own. This rule is reminiscent of the *Belief Transfer Rule* defined by (Perrault, 1990), who states the effects of speech acts in terms of Default Logic. The *Belief Transfer* rule says that if one agent believes that another agent believes something the first agent will come to believe it too, unless he has evidence to the contrary.

Strengthening: Strengthening a belief means converting it from a weak belief into a strong belief. A speaker's weak beliefs, expressing his expectations concerning the understanding and acceptance of an utterance that he has contributed are strengthened to become strong beliefs when the addressee provides explicit or implicit positive feedback about his processing of the utterance. A participant's believed mutual beliefs about a weak belief, are strengthened to become believed mutual beliefs about a strong belief when (1) he believes that both partners believe that the utterance was well understood by the addressee and accepted without evaluation problems; (2) he has evidence that both dialogue partners have evidence that they both have evidence that (1) is the case. An extended explanation about how strengthening applies can be found in (Bunt and Morante, 2007; Morante, 2007).

In short, from the moment that a dialogue participant creates a mutual belief about a weak belief, two non-problematic turns by the other dialogue participant are necessary. This is due to the fact that certain beliefs have to be in the context model before strengthening can take place. For example, if participant A has a mutual belief about a weak belief that p as a result of his interaction with participant B, the following beliefs have to be in the context for the strengthening of the weak belief to take place:

(1) (i) A believes that p
(ii) A believes that B believes that p
(iii) A believes that B believes that A believes that p

In the model, the creation of a mutual belief about a strengthened belief indicates that the information in the strengthened belief is grounded by the holder of the mutual belief.

Cancellation: Cancellation of a belief or goal means removing it from the context model. A goal is cancelled when it has been satisfied or proved to be unsatisfiable.

3.2 Effects of utterances in the context model

The types of effects that utterances provoke in the context model are related to understanding and adopting information.

Understanding effects: If the Addressee understands the Speaker's utterance, beliefs will be created in the Addressee's context model about the fact that he believes that the preconditions of the Speaker's utterance hold. Additionally, if the Speaker's utterance provides implicit positive feedback, beliefs will be created in the Addressee's context model about the Speaker having understood the previous Addressee's utterance(s).

Expected understanding effects: The Speaker will expect that, unless there are reasons to think

the contrary (like interferences in the communication), the Addressee understands correctly what the Speaker said, and that the Addressee understands the implicit positive feedback effects of the current utterance with respect to previous utterances. The Speaker cannot be certain about this, however, as long as he does not receive any feedback from the Addressee. This is why these beliefs are modelled as 'weak beliefs': the Speaker weakly believes that the Addressee understood the utterance and that the Addressee understood the implicit positive feedback effects of the utterance.

The Speaker will believe that the Addressee will also believe that the Speaker weakly believes that the Addressee understood the Speaker's utterance and its implicit positive feedback effects. More in general, the idea that speakers expect to be correctly understood is assumed to be shared by all speakers and addressees. That is, both Speaker and Addressee believe that it is *mutually believed* that the Speaker weakly believes that the Addressee understood the Speaker's utterance and its implicit positive feedback effects.

Mutual beliefs about weak beliefs can be converted into mutual beliefs about strong beliefs by applying the *strengthening* mechanism.

Adoption effects: If the Addressee correctly understands the Speaker's utterance, and if the Speaker's utterance contains information that the Addressee considers as trustworthy, then the Addressee will adopt this information.

Expected adoption effects: These are of the same type as the expected understanding effects, with the difference that they apply to effects of adoption instead of effects of understanding. For example, if as a result of an adoption effect Addressee *B believes that p*, the mutual beliefs about expectations of adoption on the side of Speaker A is *A believes that it is mutually believed that A weakly believes that B believes that p*. On the side of Addressee B, if processing has been correct, the same mutual belief arises: *B believes that it is mutually believed that A weakly believes that B believes that p*.

3.3 The role of feedback

DIT establishes four levels of feedback, that reflect how an utterance has been understood and how the speaker is able to react to that utterance depending on his current state of information, either positively or negatively. Negative feedback on one level implies positive feedback of the previous levels.

- *Perception* In terms of utterance processing in a dialogue system, this level is associated with successful speech recognition.
- *Interpretation* corresponds to being able to recognise the dialogue act(s) performed with the utterance.
- *Evaluation* indicates that the beliefs that result from the (preconditions of the) dialogue act identified at the interpretation level are consistent with the own information state.
- *Execution* level means being able to do something with the result of the evaluation. For example, in the case of a question, it consists of finding the information asked for; in the case of an answer, it means taking over the content of the answer.

Feedback acts express information about the feedback level reached and have consequences in the context update process. Negative autofeedback acts have as a consequence the cancellation of beliefs. An utterance U by participant A addressed to participant B in relation to B's previous utterance U_{-1} that expresses negative perception or understanding has the effect of cancelling B's beliefs created as a consequence of U_{-1}. If participant A signals that he did not perceive or understand what participant B said, it means that participant A can not have any beliefs about what B said. Consequently, B has to cancel the effects of expectations of understanding, and, if it applies, also the expectations of adoption. If U expresses negative evaluation or negative execution, then it has the effect of cancelling B's beliefs about effects of expected adoption created as a consequence of U_{-1}.

The effects of positive autofeedback acts on the belief model have as a consequence that the creation of beliefs as a result of the different types of effects proceeds as expected, and in after the necessary turns have occurred it will lead to participants creating a common ground.

4 Example dialogue

In this section, we will show how the context update model works in the case of the dialogue in (2), in which the User (U) asks the System (S) for information about how to operate a fax machine.

(2) (U1) **User**: Where should I put the paper that has to be copied?

(S2) **System**: In the feeder.

(U3) **User**: Thank you.

(S4) **System**: Sorry?

(U5) **User**: Thank you.

(S6) **System**: You're welcome.

In U1, the User puts a WH–QUESTION to the System. Questions in general have two preconditions: the speaker wants to know something and the speaker believes that the hearer has that information. In this case the User wants to know where the paper to be copied has to be put [u01][2] and the User believes that the System knows where the paper to be copied has to be put [u02].

After U1, the User expects that the System has understood his utterance, which is modelled as a weak belief that the System believes that the preconditions of the WH–QUESTION hold for the User. Recall that this belief is weak, because the User did not yet receive any positive feedback from the System. The effects of expected understanding also stated that this expectation is believed to be mutually believed by both User and System. All of this results in the creation of beliefs [u1,u2] in the User's context model and beliefs [s1,s2] in the System's context model.

Besides the effects of expected understanding as indicated above, also effects of understanding the WH–QUESTION apply in updating the System's context model. This results in the System believing that the User wants to know something and that the User believes that the System knows it [s1,s2].

Because the dialogue act belongs to the task-domain dimension, the beliefs resulting from utterance U1 are are recorded in the System's *Semantic Context*. Belief [s1] involves a user goal and forms a trigger for the System to generate a task-domain dialogue act in order to satisfy this goal. In the example, the System has been able to find the information it believes the user wants, and produces S2.

S2 is a WH–ANSWER by the System that answers the question put in U1, and at the same time gives implicit positive feedback to the User: the User may now conclude that the System understood U1 because the System has given a relevant reply. This understanding effect results in the beliefs [u3, u4]. The effect of the User understanding the System's answer results in [u5], i.e., the User believes that the System believes that the paper should be inserted in the feeder. Additionally, having successfully evaluated the answer and assuming the System is cooperative and a domain expert, the User adopts the information given by the System and now himself believes that the paper has to be put in the feeder [u6]. Now having the information he asked for in U1, the User can cancel the corresponding goal [u01].

In addition to these understanding effects, there are effects of expected understanding, i.e., both System and User believe that it is mutually believed that the System expects his utterance S2 to be understood. Again, this expectation is modelled via a weak belief, in this case, a weak belief by the System. Understanding S2 here includes both understanding the answer as such and the effects of implied positive feedback. Hence, in the User's context model we get beliefs [u7] to [u9] and in the System's context model [s5] to [s7]. On top of that, in the context models of both System and User, effects of expected adoption apply, i.e., they now both believe that it is mutually believed that the User will adopt the information provided by the System in S2 ([u10] and [s8]).

In U3 the User thanks the System with a THANKING function from the SOM dimension. He updates his context model with expected understanding effects, i.e., he expects that the System will interpret U3 as providing implied positive feedback about S2. This means that the User expects the System to believe that the User fully understood S2, as expressed in [u3] to [u6]. Together with the assumption that this is mutually believed, this results in beliefs [u11] to [u14] in the User's context model.

However, the System could not successfully process U3. Updating the context model with this event

[2] The numbers between brackets refer to belief numbers used in Table 1 below.

results in recording a perception level processing problem in the *Cognitive Context*. In the absence of an interpretation of U3 in terms of dialogue acts, no beliefs are created in the context of the System. The perception problem is the motivation for the System to produce a NEGATIVE AUTOFEEDBACK PERCEPTION dialogue act in S4. After successful interpretation of S4 as this negative feedback act, the User has to cancel his beliefs about expecting the System to understand U3: [u11] to [u14]. As a consequence of S4 the User repeats U3 in U5.

U5 has the same effects in the User's context as U3: [u11] to [u14]. Additionally, it has effects in the System's context model because now the System correctly understood. The THANKING function has the effect of creating a so-called reactive pressure in the Social Context, which will be released in utterance S6. A THANKING function has also effects of implicit positive feedback, resulting in the System believing that the User fully understood S2, as expressed in beliefs [u3] to [u6]. Hence, the System creates beliefs [s9] to [s12] in his context model. Because the System now successfully processed U5, he also creates beliefs about the User expecting the System to fully understand U5: [s13] to [s16].

In S6 the System responds to the User's thanks with a THANKING-DOWNPLAY function, releasing the reactive pressure created after U5. The dialogue act also implies positive feedback, causing the corresponding effects of understanding in the User's context model: the User now believes that the System understood U5, as expressed by beliefs [s9] to [s10], resulting in the User's beliefs [u15] to [u18].

There are also effects of expected understanding in both participants' context models. Both User and System believe that it is mutually believed that the System expects S6 to be understood by the User, including the implied positive feedback provided. This leads to beliefs [s17] to [s20] in the System's context model, and [u19] to [u22] in the User's context model.

On top of that, this utterance has the effect of creating two more beliefs in the User's context model, [u23] and [u24], which are the result of strengthening beliefs [u1] and [u2]. So now the User now believes that it is mutually believed that the User (strongly, instead of weakly) believes that the System understood the initial User's question U1. The strengthening is justified by the presence of the beliefs [u3], [u4], [u15], and [u16].

Let us analyse the strengthening of belief [u1], expressing that "the User believes that it is mutually believed that the User weakly believes that the System believes that the User wants to know where he should put the paper to be copied". In [u1], the weak belief is about a System's belief, so the User cannot convert this into a strong belief until the System gives some positive feedback, implicit or explicit. This happens in S2, where the System replies with a WH–ANSWER that is relevant for the User's question. This is why the User creates then belief [u3], "the User believes that the System believes that the User wants to know where he should put the paper to be copied", which corresponds to (i) in the required beliefs for strengthening listed in (1).

Because in this case [s1] is a belief by the System ("System believes that the User wants to know where he should put the paper to be copied"), (i) and (ii) in (1) are expressed by the same belief, [u3]. Case (ii) should be: "the User believes that the System believes that System believes that the User wants to know where he should put the paper to be copied". We consider "the System believes that System believes" to be equivalent to "the System believes". Case (iii) in (1) is belief [u15], created after S6: "the User believes that the System believes that the User believes that the System believes that the User wants to know where he should put the paper to be copied".

5 Conclusions

We have presented a model for context updating in dialogue. The model provides an exact specification of how the participants' belief states evolve during a dialogue. The utterances produced are specified in terms of dialogue acts and have several types of effects on the belief states.

The context update model has been implemented in a dialogue manager that operates within an interactive question answering system. The input to the context update algorithm (Keizer and Morante, 2006) is an abstract representation of a system or user utterance. In the case of a user utterance, this representation is the result of the output produced by the various language analysis components. This

consists of meta-information in the form of an understanding level reached. If there was successful dialogue act recognition, i.e., at least interpretation level understanding was reached, the representation will also contain a set of dialogue acts. In the case of a system utterance, the underlying dialogue acts are generated by the system himself, and therefore, the abstract representation will only consist of these dialogue acts.

The rich information in the context model allows us to experiment with dialogue act generation mechanisms for dialogues that are more complex both in the sense of flexible task execution and dealing with communication problems. For example, the common ground information in the System's context can be taken into account in order to decide if information has to be presented to the user as new or as known. Besides dialogue act generation, another interesting topic for future work is making the dialogue manager more powerful by enabling it to reason about the beliefs in the context model.

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Table 1: Analysis of the dialogue in Example 2.

Beliefs are numbered in columns 1 and 4 (**num**); the type of belief is indicated in columns 2 and 5 (**type**): precondition (prec); understanding effects (und); adoption effects (ad); expected understanding (exp.und); expected adoption (exp.ad). Operations on beliefs are indicated by *operation:number*, where *ad*, *ca* and *st* stand for adoption, cancellation and strengthening. Columns 3 and 6 contain the System's and User's beliefs. 'BEL_MBEL' stands for 'believes that it is mutually believed', 'WBEL' stands for 'weakly believes', and 'BEL' stand for 'believes'.

num	type	beliefs System	num	type	beliefs User
			u01	prec	WANT(U,KNOW(U,LOCATION_OF_PAPER))
			u02	prec	BEL(U,KNOW(S,LOCATION_OF_PAPER))
(U1) User: Where should I put the paper that has to be copied?					
s1	und.	BEL(S,u01)			
s2	und.	BEL(S,u02)			
s3	exp.und.	BEL_MBEL(S,WBEL(U,s1))	u1	exp.und.	BEL_MBEL(U,WBEL(U,s1))
s4	exp.und.	BEL_MBEL(S,WBEL(U,s2))	u2	exp.und.	BEL_MBEL(U,WBEL(U,s2))
s01	prec	BEL(S,LOCATION_OF_PAPER IS FEEDER)			
(S2) System: In the feeder.					
			u3	und.	BEL(U,s1)
			u4	und.	BEL(U,s2)
			u5	und.	BEL(U,s01)
			u6	ad:u5	BEL(U,LOCATION_OF_PAPER IS FEEDER)
s5	exp.und	BEL_MBEL(S,WBEL(S,u3))	u7	exp.und.	BEL_MBEL(U,WBEL(S,u3))
s6	exp.und	BEL_MBEL(S,WBEL(S,u4))	u8	exp.und.	BEL_MBEL(U,WBEL(S,u4))
s7	exp.und	BEL_MBEL(S,WBEL(S,u5))	u9	exp.und.	BEL_MBEL(U,WBEL(S,u5))
s8	exp.ad	BEL_MBEL(S,WBEL(S,u6))	u10	exp.ad	BEL_MBEL(U,WBEL(S,u6))
				ca:u01	
(U3) User: Thank you.					
		perception problems	u11	exp.und	BEL_MBEL(U,WBEL(U,BEL(S,u3)))
			u12	exp.und	BEL_MBEL(U,WBEL(U,BEL(S,u4)))
			u13	exp.und	BEL_MBEL(U,WBEL(U,BEL(S,u5)))
			u14	exp.und	BEL_MBEL(U,WBEL(U,BEL(S,u6)))
(S4) System: Sorry?					
				ca:	u11 to u14
(U5) User: Thank you.					
s9	und	BEL(S,u3)			
s10	und.	BEL(S,u4)			
s11	und.	BEL(S,u5)			
s12	und.	BEL(S,u6)			
s13	exp.und	BEL_MBEL(S,WBEL(U,s9))	u11	exp.und	BEL_MBEL(U,WBEL(U,s9))
s14	exp.und	BEL_MBEL(S,WBEL(U,s10))	u12	exp.und	BEL_MBEL(U,WBEL(U,s10))
s15	exp.und	BEL_MBEL(S,WBEL(U,s11))	u13	exp.und	BEL_MBEL(U,WBEL(U,s11))
s16	exp.und	BEL_MBEL(S,WBEL(U,s12))	u14	exp.und	BEL_MBEL(U,WBEL(U,s12))
(S6) System: You're welcome.					
			u15	und.	BEL(U,s9)
			u16	und.	BEL(U,s10)
			u17	und.	BEL(U,s11)
			u18	und.	BEL(U,s12)
s17	exp.und	BEL_MBEL(S,WBEL(S,u15))	u19	exp.und	BEL_MBEL(U,WBEL(S,u15))
s18	exp.und	BEL_MBEL(S,WBEL(S,u16))	u20	exp.und	BEL_MBEL(U,WBEL(S,u16))
s19	exp.und	BEL_MBEL(S,WBEL(S,u17))	u21	exp.und	BEL_MBEL(U,WBEL(S,u17))
s20	exp.und	BEL_MBEL(S,WBEL(S,u18))	u22	exp.und	BEL_MBEL(U,WBEL(S,u18))
			u23	st:u1	BEL_MBEL(U,BEL(U,s1))
			u24	st:u2	BEL_MBEL(U,BEL(U,s2))