Incremental Information State Updates in an Obligation-Driven Dialogue Model

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Abstract

We sketch the outlines of a dialogue model using DISCOURSE OBLIGATIONS in a formal framework of INFORMATION STATES. We propose a set of practical inference rules which incrementally update information states and assign intentional structures to sequences of dialogue moves. In this way we show that an obligation-driven approach can account for a wide range of phenomena which are assumed to be crucial for modelling any kind of dialogue. In particular, our analysis will focus on providing a treatment of questions and assertions in dialogue, thus covering some of the basic reasoning processes involved in information-oriented interaction.

1 Introduction

In recent years, the idea of modelling dialogue in a formal framework of INFORMATION STATES (ISs) has gained more and more interest. Of particular importance in this context is the work of Poesio & Traum (see for example [25]) and the research carried out by the TRINDI consortium,[1] which has focussed on the assumption that some of the basic reasoning processes involved in human interaction can be modelled in terms of INFORMATION STATE UPDATES (see [1], [2], [27] and [9] for detailed discussions of the notion of information states in the TRINDI project).

Here, we start with a dialogue model using DISCOURSE OBLIGATIONS as the basic expressive means for modelling the coherence between the actions of dialogue participants (DPs) (see [26] for the fundamental arguments motivating the use of obligations). We then propose a set of practical inference rules operating on multiple levels of ISs which incrementally update ISs and assign a structure reflecting the relationships between the DPs' intentions at a given state in the dialogue. We suggest that this demonstrates that a 'bottom-up' approach to dialogue modelling, as implied by the notion of discourse obligations, yields results at the descriptive level that are equivalent to those proposed in intention-based accounts while proving to be superior in terms of explanatory power.

Our argument will particularly focus on the treatment of questions and assertions in dialogue, an issue that has attracted a lot of attention in formal semantics research as well as in computational theories of human interaction. In this respect, Ginzburg's

[1] Telematics Applications Programme, Language Engineering Project LE4-8314.

work on the semantics of questions ([10], [11]) has proved to be very influential in dialogue modelling (see [20] and [8] for applications of the theoretical approach). However, as Kreutel & Matheson ([17]) have demonstrated, the basic structuring aspects of Ginzburg's notion of QUESTION UNDER DISCUSSION can be reformulated in an obligation-driven framework. With the basic model in [17] as a starting point, the formalisation of our analysis in terms of the TRINDI framework thus aims to provide further support for the notion that a model using ISs and discourse obligations provides an attractive basis for dialogue related research.

The data used here to illustrate the model are all hand-written. However, we assume that the phenomena under discussion are sufficiently common that an in-depth corpus analysis is not necessary at this stage. We also accept that the range of speech acts we present is limited. Again, though, we argue that central issues such as the relationship between questions and answers merit particular attention, while accepting that it is desirable to extend the model in this respect. Another point to note is that we are not suggesting that our interpretation of the data is the only possible one; in most cases different intonation contours, for example, are directly associated with different interpretations. We merely suggest that the interpretation we assign is possible and commonplace.

We will first introduce our notion of IS and give a brief overview of the basic components. We then formulate the practical inference rules which incrementally update the multiple IS components. Finally, we provide a detailed example of the IS updates involved in question-answer sequences.

2 Information States and Component Structures

The basic assumption behind the notion of information states is that, from a very general position, it is useful to view dialogues in terms of the relevant information that the dialogue participants have at each stage in the discourse. The main effect of an utterance is thus to change this information, and an obvious question is what kind of information is involved in this process. Among other things, viewing utterances in terms of the way they update ISs allows a decomposition of the classical notion of DIALOGUE MOVE, as employed, for instance, in the framework of CONVERSATIONAL GAME THEORY (see for example [5]). According to this point of view, dialogue moves can be seen as performing multiple actions which affect various levels of the information structure in dialogue.

The representation of ISs in the TRINDI project is generally done using feature structures displayed as attribute-value matrices (AVMs) to represent the components that are assumed to constitute the DPs' knowledge of 'the state the dialogue is in', and we continue this usage here. In our obligation-driven model, the basic component of an IS is a representation of the common ground which is assumed to have been established by the DPs, and this contains a representation of the obligations that are imposed on them (see [17] for some background work). We must emphasise that we are not attempting to describe the process of grounding here; see [6], [25], [22] for relevant work. The grounding model assumed by Poesio and Traum ([25]) is compatible with our analysis and we intend to expand our model to include it in future. We do retain a ground field in our IS representation as a place-holder for this extension. This field also holds a representation of the history of the dialogue,

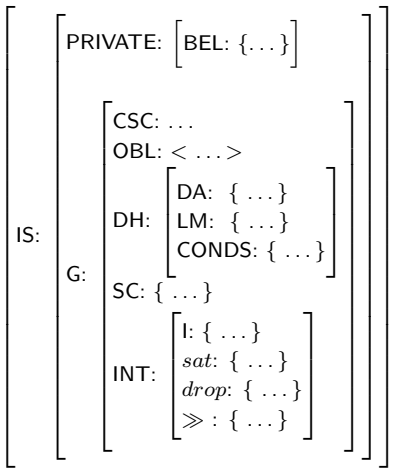

FIG. 1. Information State Structure

which following Poesio & Traum means a structure containing the DIALOGUE ACTS representing the main contents of utterances.

For current purposes, then, we assume a simple IS model with no grounding mechanism, in which case the DPs' private beliefs only consist of sets of propositions and do not include assumptions about the course of the interaction. With respect to the latter, we assume that all the information arising during the dialogue belongs to the shared beliefs of the DPs and is represented in the common ground (G in Figure 1). The main components of G which we require in this context are a stack of obligations (OBL), a structured representation of the dialogue history (DH), a set of propositions which capture the DPs' social commitments[2] as these arise in the course of the interaction (SC), a representation of the intentional structure of the discourse (INT), and finally the 'current scenario' (CSC) attribute, which describes the particular context that the IS as a whole represents and allows a simpler statement of update rules.

It should be noted that the IS in Figure 1 is common to all the dialogue participants; this is not necessary, and in fact the Poesio & Traum approach which we are adopting assumes a separate structure representing the IS of each participant. However, as we are not attempting here to model such phenomena as misunderstandings arising from differing views of what has been grounded, we can use a single representation.

The following sections provide a brief description of the important aspects of the IS components introduced above.

2.1 Dialogue History (DH) and Dialogue Acts (DA)

We adopt Poesio & Traum's idea that moves in a dialogue involve the performance of actions at multiple levels of discourse structure, and that these actions can be decomposed into DIALOGUE ACTS. Following [25], we accept the argument that any speech act may appear in a wider discourse context and thus subclassify dialogue acts

[2]We follow Poesio & Traum in distinguishing obligations and commitments; one suggestion is that obligations can be imposed by another DP, while commitments cannot.

Core Speech Acts

$assert(A, p)$	A asserts that p holds.
$ask(A, B, q)$	A asks B a question with content q.
$accept(A, m)$	A accepts the assertion performed in move m.
$reject(A, m)$	A rejects the assertion performed in m.
$accept\_answer(A, m, n)$	A accepts m as an answer to the question performed in n.
$drop\_question(A, m)$	A drops the question performed in m.

Argumentation Acts

$address(A, m)$	A expresses a statement regarding the assertion performed in m
$correct(A, m)$	A corrects the assertion performed in m.
$request\_evid(A, m)$	A requests evidence for m.
$answer(A, m)$	A means to provide an answer to m.
$info\_request(A, m)$	A asks a question in order to come up with an answer for m.
$reject\_answerhood(A, m, n)$	A rejects m as an assertion that resolves n.

FIG. 2. Dialogue Act Classification

into CORE SPEECH ACTS and ARGUMENTATION ACTS, where the latter characterise the context-dependent actions of core speech acts.

For modelling questions and assertions in dialogue, which as we have noted is our main concern, we assume the dialogue acts shown in Figure 2. This classification generally follows the proposal outlined in [17], according to which the evaluation of an assertion which is meant as the answer to a question should be seen as a two-fold process involving firstly the 'assertive' and secondly the 'answerhood' properties of the assertion, where the second stage is characterised by an *accept_answer*, *reject_answerhood*, or *drop_question* dialogue act.

This analysis is motivated by examples such as the one below, in which the ASKEE (A) needs two attempts to answer a question:

Example 2.1

A[1]:	Helen did not come to the Party.
B[2]:	How do you know that?
A[3]:	Her car wasn't there.
B[4/5]:	Ok. But she could have come by bicycle.
A[6]:	I stayed there until 4 o'clock in the morning and she didn't show up.
B[7]:	Ok.

Here, B's turn in B[4/5] expresses acceptance of the assertive content of A[3], but at the same time rejects A[3] as an assertion which resolves the request for evidence in B[2]. A then comes up with an alternative answer which now is accepted by B's *ok*

in B[7], both as an assertion *and* as an answer to B[2]. According to our analysis, B[7] constitutes a move performing the two core speech acts *accept* and *accept_answer*.[3] In contrast, we assume that B in B[4/5] performs an *accept* and an *assert* core speech act and a *reject_answerhood* argumentation act.

Another possible way for an asker to evaluate an answer to a question is shown in example 2.2 below. Here, the asker expresses an inability to come up with an answer. A's *ok*, then, can be analysed not only as an acceptance of the assertive content of B[2], but also as signalling that the initial question has been dropped for the remainder of the conversation:

Example 2.2
A[1]: Did Pete show up at the party?
B[2]: I don't know.
A[3]: Ok.

In our analysis *accept_answer* as well as *drop_question* are analysed as core speech acts. This is due to the taxonomic assumption that the opening and closing acts of interaction patterns such as the subdialogues initiated by questions or assertions constitute core speech acts. In Poesio & Traum's terms this view can be expressed by the claim that for each FORWARD-LOOKING dialogue act there is a set of BACKWARD-LOOKING acts, where the latter represent possible actions to close the subdialogues initiated by the former.[4] Note however that *reject_answerhood* produces an iteration of the answering process, causing the askee to come up with an alternative answer to the initial question.

We assume that the 'latest move' field IS.G.DH.LM[5] holds all the dialogue acts assigned to the move that is currently being interpreted at any stage in a conversation. Our formal description of the update mechanism in section 3.2 will describe in detail the way the content of this field is managed in the course of a dialogue.

Notice that the dialogue history also contains the field IS.G.DH.CONDS, which contains conditionals that are introduced by the performance of certain dialogue acts, for example the request for evidence in example 2.1 above, repeated here as 2.3:

Example 2.3
A[1]: Helen did not come to the Party.
B[2]: How do you know that?

In order to model the effect of B[2] on the IS in an appropriate and intuitive way, we assume that requests for evidence introduce a conditional stating that the acceptance of the answer that A provides for B[2] will also count as B's acceptance of the assertion in A[1]. Dealing with this kind of relationship between two dialogue acts by means

[3] The attribution of core acts to utterances is not a straightforward issue, as many people have pointed out (see for instance [21]). For current purposes we are assuming a tight relationship between linguistic form and core speech act; this is too simplistic, and one of the issues we are addressing for future work is exactly how this relationship should be characterised.

[4] The terms 'forward-looking' and 'backward-looking' refer to the classification of dialogue acts provided initially by the Discourse Resource Initiative ([15]). Roughly speaking, a backward-looking act is one which is triggered by a previous act, and which must therefore be interpreted in the context of the previous dialogue. Note that this condition also holds for argumentation acts like *answer* or *reject_answerhood*. However, these acts differ significantly from acceptance acts in that they cannot close interaction sequences.

[5] Paths in AVMs are represented here as attribute names separated by fullstops; so IS.G.OBL picks out the field which represents obligations, and so on.

of explicitly adding conditionals to the IS (rather than by, for example, handling the dependency directly in an update rule) is motivated by the possibility that the DPs may consider the content of this conditional when planning their actions, for instance in the discussion scenario in example 2.4 below:

Example 2.4
A[1]: Jack and Helen will split very soon.
B[2]: That's not true.
A[3]: But she didn't come to his party.
B[4]: How do you know that?
A[5]: Her car wasn't there.

Here, B's accepting A[5] as an answer to B[4] would conditionally trigger acceptance of A[3] as well, thus supporting A's claim in A[1] (given that B considers Helen's absence as hinting at a crisis in her relationship with Jack). As B knows about this relation between the acceptance of A[5] and A[3], pursuing the intention motivating B[2] might result in B's rejecting A[5] as evidence for A[3], in which case A would have to come up with yet another alternative answer.[6]

2.2 Discourse Obligations (OBL)

Discourse obligations model some aspects of dialogue which are assumed to be essentially social in nature. Our use of this concept largely follows the work of Traum & Allen [26], where it is argued that a purely intention-based account of interactions cannot explain why dialogue participants do anything in situations where they are unwilling or unable to adopt the speaker's intentions. By setting dialogue in a social context Traum & Allen are able to provide mechanisms, in the form of obligations, which prompt the participants' behaviour in circumstances such as the following:

Example 2.5
A[1]: Did Pete drive here?
B[2]: I don't know / I don't want to talk about that

Traum & Allen argue that intention-based dialogue models fail to explain why B responds to A's question with either reply in example 2.5. Briefly, this is because the hearer must adopt the speaker's intentions, and if intentions are formalised as achievable goals then this is impossible when the hearer cannot or will not form the goal. In these circumstances there is no intention-driven explanation of why B responds at all in example 2.5. An obligation-driven approach, on the other hand, predicts B's behaviour appropriately by assuming that participants in a dialogue are socially *obliged* to respond, no matter what their intentions are.

Whereas most approaches using discourse obligations preserve a representation of the DPs' intentions, Kreutel & Matheson ([17]) propose a dialogue model which captures a range of subdialogues initiated by questions or assertions by exclusively referring to the obligations imposed on the DPs, leaving aside their intentions.[7] Conceiving thus of cooperativity as the DPs' willingness to act according to the obligations

[6] See [19] for an outline of how strategic scenarios like discussions can be modelled in the framework of an obligation-driven dialogue model.

[7] We are not, of course, suggesting that intentions have no place in the representation of dialogues; just that they are not the sole driving force behind utterances.

imposed on them, obligations are established as the basic explanatory means which reconstruct the essentially rule-governed behaviour exhibited by cooperative DPs.

The model in [17] assumes that the obligation to *answer* a question q that is introduced by an *ask* act will persist until the asker accepts an *answer* act by the askee as one which resolves q. Following this approach, the repetition of an attempt to come up with an answer to a question, as in example 2.1 above, can easily be motivated by the assumption that the obligation introduced by an initial question is still present in IS.G.OBL after an *answer* act has been performed:

Example 2.6

A[3]:	Her car wasn't there.
B[4/5]:	Ok. But she could have come by bicycle.
A[6]:	I stayed there until 4 o'clock in the morning and she didn't show up.

However, this treatment implies a rather counterintuitive notion of obligations as 'social objects that are under control of the dialogue participants', subject to the mental state with respect to which the resolution of a question is defined (see [10] and [11]). Furthermore, the model claims that, contrary to the obligation to *answer* a question, the obligation to *address* an assertion is discarded by any kind of reply, which means that there can be no generic rule for downdating the obligation stack.

Facing these shortcomings, here we aim at a consistent treatment of obligations which does not take into account the obligation-introducing dialogue act when deciding about a downdate of IS.G.OBL. Hence, we assume that an obligation is discarded whenever an act is performed which matches its content. As we will show below, actions such as A's repeated answer in example 2.1 can then be modelled by assuming that the *reject_answerhood* act results in a reintroduction of the original obligation to answer the question.

2.3 Commitments (SC)

Generalising a proposal in [27], we assume that an IS contains a representation of the commitments of the DPs as these arise in the course of the interaction. However, whereas the SCP attribute in the latter work only contains commitments referring to the propositional contents of assertive acts, we propose to extend this notion and use IS.G.SC also to represent information about the way questions have to be dealt with by the dialogue participants. We therefore assume that IS.G.SC contains propositions which express the status that the contents of assertions or questions have in the discourse; for example, that the content of an assertion counts as shared belief or that a question should be considered as resolved for the remainder of the conversation.

This way, IS.G.SC can be seen as limiting the range of admissible topic-raising actions in the course of a conversation. Making an assertion whose content is already represented as shared belief or asking a question which is assumed to have been resolved can be seen as violating the principle that contributions to the discourse must be informative.[8]

[8] See the Gricean maxim of quantity in [13].

2.4 Intentional Structure (INT)

The first thing to note about our use of INT in comparison, for instance, to [22], is that we are not dealing with private intentions which, in the case of the latter paper, would be represented here by the path IS.INT. Rather we are dealing with the hearer's reconstruction of the intentions behind the speaker's actions, and representing these in IS.G.INT. In our model, IS.G.INT is built up by means of inference rules given the information in the dialogue history. Taking this approach we assume that from the occurrence of certain dialogue acts the DPs can infer each other's intentions and the way they are managed (whether they are satisfied, dropped, and so on).

It should also be noted that we assume that intentions are objects that are individualised with respect to the DPs; different DPs can intend to do the same thing, but these are of course different intentions. As far as the contents of intentions are concerned, however, we consider them to be propositions expressing the status of an assertion or a question in the current discourse. Intentional structure is thus conceived of as constituted by interactive goals which are to be achieved in the course of the discourse. The contents of the intentions associated with assertions and questions are assumed to be the goals *shared_belief(p)* and *resolved(q)*, where p and q are the contents of the assertion and the question, respectively.[9]

Formally, we represent IS.G.INT as a structure that consists of the four substructures I, $\gg$, *sat*, and *drop*, where I is a set of the DPs' intentions, $\gg$ is the two-place relation of *immediate dominance* in I, and *sat* and *drop* are 1-place relations in I that correspond to the sets of satisfied and dropped intentions. The relation $\gg$ is defined as follows:

Immediate Dominance

$i_j \gg i_k$ iff i_j and i_k are members of I, $i_j > i_k$ and there is no i_m in I such that $i_j > i_m$ and $i_m > i_k$, where $>$, the relation of *dominance*, is defined as proposed by Grosz & Sidner ([14]).[10]

Example 2.7 below shows the contents of IS.G.INT following a simple question-answer sequence:

Example 2.7

A[1]: Did Helen come to the Party?
B[2]: Yes.
A[3]: Ok. Thanks.

$$\left[\begin{array}{l}\textsf{INT:} \left[\begin{array}{l}\textsf{I:} \left\{\begin{array}{l} i_1 : resolved(?helen\_at\_party)_A, \\ i_2 : resolved(?helen\_at\_party)_B, \\ i_3 : shared\_belief(helen\_at\_party)_B \end{array}\right\} \\ sat\text{: } \{i_3,i_2,i_1\} \\ drop\text{: } \{\ \} \\ \gg : \{(i_1,i_2),(i_2,i_3)\} \end{array}\right] \end{array}\right]$$

[9] These are not of course the only possible goals associated with assertions and questions; it cannot be assumed, for instance, that asking a question necessarily entails an intention for the question to be resolved. However, for the purposes of outlining the basic model, we suggest that a simple one-to-one mapping between dialogue acts and intentions is sufficient.

[10] According to [14], an intention i_1 *dominates* an intention i_2 iff an action that satisfies i_2 also contributes to the satisfaction of i_1.

We assume that the intentions associated with dialogue acts reformulate the idea that an askee adopts an asker's desire for information when answering a question (see [7]): i_1 and i_2 are identical with respect to their content, but individualised over the two DPs. The representation in IS.G.INT also captures the notion that the intention i_3 associated with the assertion in B[2], which is offered as an answer to the question, is *dominated* by the askee's intention that the question should be resolved, and thus significantly differs from a discourse-initial assertion due to its context. As i_1 and i_2 have the same content, satisfaction of the latter by A's acceptance of B's answer automatically means satisfaction of i_1.

2.5 Update Scenarios (CSC)

As discussed in section 3 below, we assume that some ISs constitute particular INFORMATION STATE UPDATE SCENARIOS as proposed in [16] and further developed in [17]. These scenarios specify certain 'constellations' of IS, corresponding to situations such as the turnholder's responding to a question, or evaluating an assertion with respect to its assertive or answerhood properties.

In our model scenarios provide a formalisation of 'discourse context' and thus constitute a basic expressive means for assigning context-dependent interpretations to the core speech acts performed by the DPs. It is important to keep in mind that each scenario is defined just on the information in IS.G.OBL and IS.G.DH, and hence the context is determined only in terms of the overall structure of the DPs' obligations and the history of the dialogue.[11] Hence it is not necessary to take into account the state of the intentional structure when updating the scenario. This way, our model maintains the basic assumption of [17], according to which in cooperative scenarios the behaviour of DPs can be modelled on the basis of their observable actions and does not require reasoning over intentions.

Apart from modelling discourse context in a way which allows us to determine the argumentation acts that are performed in a move, our notion of update scenarios additionally enables us to model the way turntaking is managed in the course of a conversation. In our formalisation, scenarios are represented as predicates which express relations between a DP and a dialogue move, so for example $reply\_question(A, m)$ expresses the fact that DP A is in a situation in which a reply to some move m, in which a question has been posed, is required. Hence the turn here is assigned to A. Thus our scenarios can predict the way turntaking takes place in the dialogue in example 2.8 below:

[11] In our formal representation of ISs, we use the IS.G.CSC attribute to maintain a representation of the particular scenario which the IS represents as shorthand for the full definition.

Example 2.8

A[1]: Did Helen come to the Party?
B[2]: Did Jack come?
A[3]: Yes.
B[4/5]: Ok. Then Helen didn't come.
A[6]: Ok.

Here, B's *ok* in B[4] accepts A[3] as an assertion which resolves the question posed in B[2]. In neutral contexts such as the situation following A's *ok* in A[6], the turn now can change back to the other DP. However, in the context that results from the performance of B[4] it is the obligation introduced by A[1] which determines the scenario as one in which B has to come up with an answer to A's initial question. B therefore keeps the turn and acts accordingly.

2.6 Semantics for the Model

To provide a formal semantics for a dialogue model using information states, Poesio & Traum ([24]) propose a complete formalisation of their notion of IS in the framework of COMPOSITIONAL DISCOURSE REPRESENTATION THEORY (see [23]). We assume that the model outlined here fits in with the general assumptions in [24] and that its semantics are therefore described by Poesio & Traum's semantics for IS and IS updates. In particular, we follow the conception of moves in a dialogue as CONVERSATIONAL EVENTS and of the dialogue acts into which a move can be decomposed as properties of the latter. Our rules below therefore use the notation $ce : action$ to indicate that a move *ce* is a realisation of a particular dialogue act.

As far as the semantics of questions and assertions is concerned, we assume our model to be compatible with Ginzburg's proposals in [10] and [11]. An important issue in this context is that further extensions of our basic model should be able to operate with Ginzburg's notion of ABOUTNESS, which formalises intuitive assumptions about thematic relatedness between the semantic contents of assertions and questions. Another, more concrete, approach to defining the semantic relationships between questions and answers which we assume is compatible with our work is suggested by Bos & Gabsdil, who provide a formal definition of what counts as a 'proper' answer to a question ([4]).

3 Information State Updates

Given the concept of information states outlined above, updates can be formalised as operations which may be as simple as pushing values into the components of an IS. Popping the contents of a component would be another basic update which serves, for example, to capture the notion of an obligation being discarded. However, in more elaborated models of ISs the updates can be much more complicated, involving pushing whole new structures into the IS and operations such as the merging of parts of the IS. The latter merge operation is used by Poesio & Traum in cases where information which is not considered part of the common ground gets acknowledged. In these circumstances Poesio & Traum assume that the grounding process merges the ungrounded material with the information in the common ground.

For any move m that occurs in a given scenario sc:

I Determine $CSA(m)$, the core speech act performed in m.

II If $CSA(m)$ is a forward-looking act: Interpret $CSA(m)$ in the context of *sc*.

III Apply the context independent update rules to any argumentation act $AA(m)$ that might result from the occurrence of m in *sc*.

IV Apply the context independent update rules to $CSA(m)$.

V Determine the new context that results from the occurrence of m.

FIG. 3. Incremental update of information states

With respect to the updating of ISs, Kreutel & Matheson ([17]), in common with many other approaches to dialogue modelling, simply assume that updates involve the updating of all the components of an IS, which in the simple model in [17] means the dialogue history and the obligations. Further, although previous models assume a distinction between core speech acts and context dependent argumentation acts, there seems to be no clear notion of how the context dependent aspects could be determined formally. We suggest that the strategy for updating ISs in [17] is ultimately arbitrary and imprecise in terms of the formal aspects as well as in terms of the explanatory adequacy of the update model. Here, therefore, we propose a modularised approach to IS updates which assumes an incremental updating process, clearly distinguishing the context dependent from the context independent aspects of an update. As noted above, in formalising the context of an update, we employ the notion of update scenarios to characterise particular kinds of IS, and we use the IS.G.CSC attribute to represent this information.

The following two sections will first provide an informal discussion of some data which motivate the update algorithm we are assuming and then spell out the algorithm in detail.

3.1 Incremental Updates and Context Accommodation

We assume that, after each move, information about what kind of core speech act has been performed will be added to the IS field containing information about the latest move which has been observed (IS.G.DH.LM). The IS will thus contain information about whether an assertion has been made or whether a question has been asked. Updating can then be defined in terms of rules which operate on the IS and enrich the information contained in the different substructures; Figure 3 shows the steps assumed in our update process.

Given this update strategy, we can reconstruct the dialogue state after B's move B[2] in the question-answer sequence in example 2.7 (repeated below as 3.1) in an intuitive way:

Example 3.1

A[1]: Did Helen come to the Party?
B[2]: Yes.

As the context in which B[2] takes place is the scenario created by a question

directed at B, B's *yes* is first of all interpreted as the assertion that Helen came to the party (step **I**). In the given scenario, this assertion counts as an answer to A's question (**II**). Thus the obligation to *answer* A[1] is dropped. In addition, given our update rules for intentional structure, we can infer from B's performance of an *answer* act the intention that the question posed in A[1] be resolved (**III**). As B[2] is an assertion, it not only introduces an obligation on A to *address* it, it also allows the inference that B's intention is that the propositional content of B[2] should count as shared belief (**IV**). In the new context created by the occurrence of B[2] as a reply to A[1] we can interpret any follow-up move by A with respect to the way it addresses the assertive properties of B[2] (**V**).

In a similar fashion, our rules for incremental IS update can handle the two moves performed by B in B[4/5] in example 2.1 above, repeated here as 3.2:

Example 3.2

A[1]: Helen did not come to the Party.
B[2]: How do you know that?
A[3]: Her car wasn't there.
B[4/5]: Ok. But she could have come by bicycle.

In the context of A's assertion in A[3], A[4] is interpreted as an *accept* core speech act (**I**). As this is a backward-looking act, context-dependent interpretation is skipped. Applying the context-independent updates results in the obligation to *address* A[3] being dropped, as well as in the satisfaction of A's intention that the absence of Helen's car be shared belief (**IV**). Having thus evaluated A[3] as an assertion, the evaluation of its answerhood properties is still pending. In this new context, which is formalised below as *reply_answer*, B's assertion (**I**) that Helen could have come by bicycle counts as a *reject_answerhood* argumentation act (**II**) which reintroduces the obligation to answer B[2] (**III**), which had been dropped due to A[3]. Additionally, B[5] introduces an obligation on A to *address* it (**IV**), thus providing A with the possibility of initiating a discussion about its propositional content before getting back to dealing with B's request for evidence.

However, whereas the update strategy proposed in Figure 3 works well for examples such as those above in which for each scenario there is a move which fits in the given context, it fails to provide an appropriate account of cases like those in examples 3.3 and 3.4 below in which an assertion is accepted implicitly (without a move such as *ok* in example 3.2, which we assume expresses the addressee's acceptance of the propositional content):[12]

Example 3.3

A[1]: Helen didn't come to the party.
B[2]: Did you see Jack?

Example 3.4

A[1]: Helen's car wasn't there.
B[2]: She could have come by bicycle.

[12] Note that we are not talking about the kind of 'lower-level' acknowledgements which signal actual understanding; there is a clear distinction between examples 3.3 and 3.4 in that 3.4 contains an implicit understanding act whereas 3.3 does not.

Given that the scenario created by an assertion is determined by the obligation on the addressee to respond to the content of the assertion (see Figure 2 above), the context dependent update rules will check whether the follow-up move expresses the addressee's acceptance, rejection or doubting of the truth of the relevant proposition. In the discourse in example 3.5 below, for instance, we can clearly assign a context-dependent interpretation to the dialogue acts in B[2a] and B[2b], classifying them as a correction and a request for evidence, respectively:

Example 3.5

A[1]: Helen didn't come to the party.
B[2a]: But I'm sure I saw her there.
B[2b]: How do you know that?

In contrast to this, moves B[2] and B[4] in examples 3.3 and 3.4 above do not allow for a similar interpretation because the utterances do not contain any evaluation of the assertive content of A[1] and A[3], respectively. However, reconstructing an intuitive reading of the examples, we can assume that B[2] and B[4] do in fact accept the preceding assertions and thus satisfy the obligations introduced by the latter, simply because there is no reason to assume the contrary.

In a similar way, in cases such as example 3.6 below, in which an asker responds to an answer with a single *ok*, we can infer acceptance of the answerhood properties of the assertion from the acceptance of its propositional content and the absence of any hint that the asker continues to consider the question as unresolved:

Example 3.6

A[1]: Helen didn't come to the party.
B[2]: How do you know that?
A[3]: Her car wasn't there.
B[4]: Ok.

Where context dependent interpretation fails to assign an interpretation to a reply in terms of an evaluation of its assertive or question-resolving content, we can therefore assume that the act performed by the addressee expresses an implicit acceptance of the relevant aspect of the assertion. The question is then whether this assumption should be treated as a default rule to be included in the set of context-dependent update rules used in the model. With respect to this issue, consider once again our example 2.1, repeated below:

Example 3.7

A[1]: Helen did not come to the Party.
B[2]: How do you know that?
A[3]: Her car wasn't there.
B[4]: She could have come by bicycle.

Here, after assuming that B[4] implicitly accepts A[3], a change of context takes place: having dealt with A[3] as an assertion, the evaluation of its answerhood properties is still pending. It is in this context that an interpretation can be assigned to B's assertion in B[4], and the effect of the explicit content of B[4] has to be determined here. In the situation where acceptance is assumed for the sake of achieving

an interpretation for some move m in a given context, m is thus retained for interpretation and is subject to our incremental update rules in the new context. We formulate this interpretation strategy in a generalised way as a principle of CONTEXT ACCOMMODATION:

Context Accommodation

For any move m that occurs in a given scenario sc_i: if assignment of an interpretation to m in sc_i fails, try to accommodate sc_i to a new context sc_{i+1} in an appropriate way by assuming implicit dialogue acts performed in m, and start interpretation of m again in sc_{i+1}.

Apart from being able to deal with implicit acceptance acts, we assume that this definition is closely related to the process of QUESTION ACCOMMODATION which is described in [8] as a formal means of dealing with the phenomenon of 'overanswering' as in the following example:

Example 3.8

A[1]: Where would you like to fly to?
B[2/3]: To Toronto. From Miami.

According to the model in [8], B's move B[3] can be interpreted appropriately if one reads it as an answer to a question such as *Which airport are you departing from?*. The context in which interpretation of B[3] succeeds thus results from accommodating the context after B[2] in a way which fits the update procedure discussed above, namely by assuming an implicit *ask* act from A to which B[3] is meant to provide an answer. Overgeneration is avoided by assuming that accommodated questions must come from the current plan, and we propose to use similar restrictions, although these are not discussed further here.

The principle of context accommodation can thus be seen as a general means of interpretation which copes with the fact that DPs tend to produce smooth and concise expressions in normal discourse. The concept is similar to the notion that the default approach to grounding is to use an 'optimistic' strategy, assuming implicit acknowledgements in the absence of counter evidence (see [3] for a discussion of the distinction between optimistic and pessimistic accounts of grounding).

The following section outlines in detail the update algorithm our model uses and also looks closely at the several kinds of inference rules we assume for modelling context dependent and independent updates.

3.2 Update Algorithm and Inference Rules

The update algorithm in Figure 4 formalises the definitions of incremental IS update and context accommodation suggested above. The basic IS component here is the field IS.G.DH.LM (latest move), which as noted above holds all the dialogue acts that are assigned to a move m.

Notice that before the actual update process starts we first try to determine the core speech act that has been performed in m, where the speech act assignment function *saa*, which we do not discuss in further detail, also takes into account the scenario in which m occurs. We then enrich the information returned by *saa* by applying the

1. Interpret m in the context of IS.G.CSC
   (a) Unless $CSA(m)$ has already been assigned:
      i. Determine $CSA(m)$
      ii. IS.G.DH.LM := $CSA(m)$
   (b) If $CSA(m)$ is a forward-looking act: Apply Context-Dependent Interpretation Rules‡

2. **if** interpretation succeeds:
   (a) $CI\_update(CSA(m))$
      i. Apply Context-Independent Interpretation Rules to $CSA(m)$
      ii. Apply Downdates Rules for obligations and intentions
      iii. Apply introduction Rules for obligations and intentions to $CSA(m)$
   (b) Resolve Conditionals‡
   (c) Update IS.G.CSC
   (d) $merge$(IS.G.DH.LM, IS.G.DH.DA)
   (e) IS.G.LM := nil

   else Apply Context Accommodation Rules‡
   (a) Resolve Conditionals‡
   (b) Update IS.G.CSC
   (c) goto step 1

‡ For any dialogue act DA added to IS.G.DH.LM: apply $CI\_update(DA)$.

FIG. 4. Update Algorithm

context dependent update rules to determine what kind of argumentation acts have been performed in m. If either speech act assignment or context dependent update fails, we try to accommodate the context assuming implicit dialogue acts, such as an implicit acceptance of an assertion. In the latter situation, in contrast to the case where context dependent interpretation succeeds, we do not merge the dialogue acts in IS.G.DH.LM with the set of previous moves in IS.G.DH.DA, but call the algorithm once again from the beginning.[13]

As the algorithm in Figure 4 states, the context-independent update rules CI_UPDATE are applied to each dialogue act separately in the reverse order of their introduction, so dialogue acts that have been determined inferentially are subject to context-independent update rules *before* the acts from which they have been inferred are processed. This approach implies a bottom-up/top-down management of processing: starting with the core speech act in a move m, we first determine the way the latter relates to the wider discourse context in which it occurs, assigning additional dialogue acts to m (bottom-up) by means of applying context-dependent updates. Once we have determined all the acts that have been performed we then apply the context-independent updates from top to bottom to each of the acts in m thus taking account of the fact that the way a core speech act influences obligations or intentional structure can only be determined accurately when we have considered the previous

[13] The merge operation that we assume is the same as that allowed by the TrindiKit, and can actually be characterised as set union for our purposes. Effectively, IS.G.DH.DA := $merge$(IS.G.DH.DA,IS.G.DH.LM).

effects of a 'higher-order' argumentation act on the context. For example, the effect an assertion has on IS.G.OBL or IS.G.INT can only be determined when we know whether m was also performing an answer act, or any other argumentation act, and when we already know the effect of this argumentation act on the context.

The following sections will spell out the practical inference rules that we assume for modelling the individual steps which make up the update process.

3.3 Context Dependent and Independent Updates

3.3.1 Context-Independent Updates

Context-independent updates in the proposed model, as the name suggests, do not take account of the current scenario, and hence operate independently of the discourse context. We assume that context-independent updates consist of a sequence of three stages involving context-independent interpretation (Figure 5),[14] the downdating of obligations and intentions (Figure 8), and finally the updating of the latter structures depending on what kind of act has been performed (Figures 6 and 7). The rules themselves are represented as lists of conditions and effects; the conditions are above the horizontal line and the effects below. Thus the first rule in Figure 5 has one condition (that IS.G.DH.LM contains an *accept* act) and two effects (add an *address* act to IS.G.DH.LM, and add an appropriate shared belief to IS.G.SC). Note also that the interpretation of $\vdash$ in the rules is actually just set membership, but we allow for a more complicated entailment in future work.

Whereas obligation and intention downdate and update rules only operate on IS.G.OBL and IS.G.INT, context-independent interpretation can affect several substructures of an IS. For example, we assume that the conditional that is associated with a request for evidence can be inferred at this point. Here we also interpret requests for evidence, acceptances and corrections as acts which *address* an assertion, expressing a DP's attitude to the propositional content of the latter. Note finally that the effects that acceptance acts have on the DPs' commitments are determined at this stage of interpretation. We currently assume the four context-independent interpretation rules in Figure 5.

The rules for the introduction of obligations in Figure 6 follow the obvious assumptions associated with questions and assertions: assertions introduce *address* obligations and questions impose an obligation on the askee to *answer*. Note that in addition to the rules in [17] we assume that a *reject_answerhood* act reintroduces the obligation which was associated with the original question.

The set of rules in Figure 7 describes the context-independent updates associated with our representation of intentional structure. We make the fairly standard assumptions that the intention behind an *assert* is that some proposition should be shared knowledge and that an *ask* act serves as an indicator that the asker wishes some question be resolved. Furthermore, our rules state that an askee's response to a question by means of an *answer* or an *info_request* act can be interpreted as the askee's adoption of the asker's intention, thus reconstructing a basic principle of cooperative rational interaction (see [7]), as noted in the discussion of example 2.7 above.

[14] For brevity, we have truncated pathnames in the rules, generally missing off IS.G so that IS.G.DH.LM, for instance, becomes DH.LM.

$\textsc{dh.lm} \vdash m : accept(A, n)$

$add(\textsc{dh.lm}, m : address(A, n))$
$add(\textsc{sc}, shared\_belief(n'))$, where n' is the content of the assertion in n.

$\textsc{dh.lm} \vdash m : correct(A, n)$

$add(\textsc{dh.lm}, m : address(A, n))$

$\textsc{dh.lm} \vdash m : request\_evid(A, n)$

$add(\textsc{dh.lm}, m : address(A, n))$
$add(\textsc{dh.conds}, p : accept\_answer(A, o, m) \rightarrow p : accept(A, n)$

$\textsc{dh.lm} \vdash m : accept\_answer(A, n, o)$

$add(\textsc{sc}, resolved(o'))$, where o' is the content of the question in o.

FIG. 5. Context-Independent Interpretation

$\textsc{dh.lm} \vdash m : assert(A, p)$

$push(\textsc{obl}, address(B, m))$

$\textsc{dh.lm} \vdash m : ask(A, B, q)$

$push(\textsc{obl}, answer(B, m))$

$\textsc{dh.lm} \vdash m : reject\_answerhood(A, n, o)$

$push(\textsc{obl}, answer(B, o))$

FIG. 6. Obligation Introduction

$\textsc{dh.lm} \vdash m : assert(A, p)$

$add(\textsc{int.i}, i_A : shared\_belief(p))$, where p is the content of the assertion.

$\textsc{dh.lm} \vdash m : ask(A, B, q)$

$add(\textsc{int.i}, i_A : resolved(q))$, where q is the content of the question.

$\textsc{dh.lm} \vdash m : answer(A, n)$

$add(\textsc{int.i}, i_A : resolved(n'))$, where n' is the content of the question in n.

$\textsc{dh.lm} \vdash m : info\_request(A, n)$

$add(\textsc{int.i}, i_A : resolved(n'))$, where n' is the content of the question in n.

FIG. 7. Intention Introduction

In addition to these relatively straightforward effects, updating intentional structure also involves integrating the intentions introduced by the rules in Figure 7 with the intention hierarchy. Here we assume the principle that intentions are always attached to the lowest attachment site possible, which in our formulation means to the last intention which has been neither satisfied nor dropped. In this way our update rules can account for the intuitive observation that the raising and addressing of topics in dialogues respect certain structural principles. Thus the representation of intentions can for example involve embedded representations, but these should not lead to crossed structures as this would involve addressing a higher-level topic before its subtopics have been sufficiently dealt with (see [14]). The following statement provides the required formalisation:

Updating the intention hierarchy

When I $\neq \{\}$ and an update of I results in an intention i_j actually being *added*

$$\frac{\textsc{obl}.[1] = a \quad \textsc{lm} \vdash a}{pop(\textsc{obl}, a)}$$

$$\frac{\textsc{int.i} \vdash i : p \quad \textsc{scs} \vdash p}{add(\textsc{int.sat}, i)}$$

FIG. 8. Obligation and Intention Downdate

to I then $\gg$ is updated in the following way: $i_k \gg i_j$ where i_k is that element of I such that $\neg sat(i_k)$ and $\neg drop(i_k)$ and for all i_m for which $i_k > i_m$: $sat(i_m)$ or $drop(i_m)$, where $sat(i_m)$ and $drop(i_m)$ stand for IS.G.INT.SAT $\vdash i_m$ and IS.G.INT.DROP $\vdash i_m$, respectively.

Finally, we include two rules for downdating IS.G.OBL and IS.G.INT in Figure 8. When discarding obligations, as already mentioned we are using the generic principle that an obligation is popped from the obligation stack whenever an action occurs which matches its content. As for intentions, on the other hand, we assume that here the DPs' commitments are the relevant structure to use in determining when an intention has been satisfied. As the contents of intentions are propositions which express an assertion's or a question's status in a conversation, intention downdate checks whether there is anything in IS.G.SC which matches the propositional content of an intention. If so, the intention is deemed to be satisfied

Having thus outlined the range of context-independent updates our model is using, the following section will describe the context-dependent aspects of the update algorithm in Figure 4.

3.3.2 Context-Dependent Updates

The formalisation of the context dependent updates that are triggered by the performance of particular dialogue acts is done on the basis of information about the update scenario in which the particular move to be interpreted has been performed. As the update algorithm in Figure 4 specifies, the current update scenario will be determined after processing each move or after context accommodation has taken place, and the rules in Figure 9 determine the required contents of IS.G.CSC. Notice that in processing an *assert* act the relevant update scenario is *respond_assert*, with no regard to whether the assertion was discourse initial or, for instance, meant as an answer to a question. However, dealing with the acceptance of an assertion involves checking whether the accepted act also constitutes the performance of an *answer* act, in which case the scenario will be set as one in which an asker's evaluation of the answerhood properties of an assertion is taking place.

In the rules for context-dependent interpretation in Figure 10 we can now refer to the scenario in IS.G.CSC when determining the argumentation acts performed in a move m. In addition to the scenario and the core speech act *csa*, the rules can refer to the propositional or interrogative content of *csa* to assess the beliefs of the relevant DP. This way, our rules allow us to distinguish the different ways the addressee of an assertion may incorporate a statement with respect to the latter's propositional

$$\frac{\text{OBL.}[1] = address(A, m)}{\text{IS.CSC} := respond\_assert(A, m)}$$

$$\frac{\text{OBL.}[1] = answer(A, m)}{\text{IS.CSC} := reply\_question(A, m)}$$

$$\frac{\text{DH.LM} \vdash m : accept(A, n) \quad \text{DH.DA} \vdash n : answer(B, o)}{\text{IS.CSC} := reply\_answer(A, n, o)}$$

FIG. 9. Update Scenarios

$$\frac{\text{IS.CSC} = reply\_question(A, m) \quad \text{DH.LM} \vdash n : assert(A, p)}{add(\text{DH.LM}, n : answer(A, m))}$$

$$\frac{\text{IS.CSC} = reply\_question(A, m) \quad \text{DH.LM} \vdash n : ask(A, B, q)}{add(\text{DH.LM}, n : info\_request(A, m))}$$

$$\frac{\text{IS.CSC} = reply\_assert(A, m) \quad \text{DH.LM} \vdash n : ask(A, B, q) \quad q \vdash Bel_A \diamond \neg m', \text{ where } m' \text{ is the content of the assertion in } m}{add(\text{DH.LM}, n : request\_evid(A, m))}$$

$$\frac{\text{IS.CSC} = reply\_assert(A, m) \quad \text{DH.LM} \vdash n : assert(A, p) \quad p \vdash Bel_A \neg m', \text{ where } m' \text{ is the content of the assertion in } m}{add(\text{DH.LM}, n : correct(A, m))}$$

$$\frac{\text{IS.CSC} = reply\_answer(A, m, n) \quad \text{DH.LM} \vdash o : assert(A, p) \quad p \vdash Bel_A \neg resolved(n'), \text{ where } n' \text{ is the content of the question in } n}{add(\text{DH.LM}, o : reject\_answerhood(A, m, n))}$$

FIG. 10. Context-Dependent Interpretation

content, for example by requesting evidence or by asserting the contrary.

In contrast to the rules for context-dependent update, all of which require the performance of a core speech act, the three rules for context accommodation in Figure 11 simply assume that some move m has occurred. We then try to exclude the conditions that are contrary to the assumption that implicit acceptance may have taken place. If we have been able to assign a core speech act *csa* to m this check is done based on the propositional or interrogative content of *csa*. Otherwise, if speech act assignment has failed, the check will always succeed. Our rules thus account for the two possible ways an interpretation of a move in a given context can fail (failure of speech act assignment or failure of context-dependent interpretation).

The last rule in Figure 11 implements accommodation in cases where no move has been performed at all (or where the turnholder just releases the turn, even though the scenario would predict that the DP who performed the last move should keep the turn). This rule allows us to assume the implicit acceptance of the answerhood properties of an assertion given the acceptance of its assertive properties as in example 3.9 below, in which a single move accepting both aspects of an assertion seems more natural than the alternative in A[3b/4]:

IS.CSC $= respond\_assert(A, m)$
DH.LM $\vdash o$
$o \not\models Bel_A \neg m'$
$o \not\models Bel_A \Diamond \neg m'$

$add(\text{DH.LM}, n : accept(m))$

IS.CSC $= reply\_answer(A, m, n)$
DH.LM $\vdash o$
$o \not\models Bel_A \neg resolved(n')$, where n' is the content of the question in n
---
$add(\text{DH.LM}, n : accept\_answer(A, m, n))$

IS.CSC $= reply\_answer(A, m, n)$
DH.LM $\vdash nil$
DH $\vdash o : accept(A, m)$, where o is the last move that has been performed by A

$add(\text{DH.LM}, o : accept\_answer(A, m, n))$

FIG. 11. Context Accommodation

Example 3.9

A[1]:	Did Pete show up at the party?
B[2]:	I don't know.
A[3a]:	Ok.
A[3b/4]:	Ok. Thanks.

Given this account of the update algorithm our dialogue model uses and the various rules involved, section 4 provides a detailed example illustrating the way IS update takes place in the course of a dialogue.

4 An Example

Here we will show in detail how our update process works for the question-answer dialogue in example 2.1, repeated below as 4.1, which has served to illustrate a number of issues above. The description will focus on the updates that are triggered by the moves numbered 4-7:

Example 4.1

A[1]:	Helen did not come to the Party.
B[2]:	How do you know that?
A[3]:	Her car wasn't there.
B[4/5]:	Ok. But she could have come by bicycle.
A[6]:	I stayed there until 4 o'clock in the morning and she didn't show up.
B[7]:	OK.

Let us first consider the IS after the updates caused by B's *ok*, shown in Figure 12.[15] The dialogue history contains all the information on core speech acts and argumentation acts that have been performed up to this point in IS.G.DH.DA, as well as the conditional introduced by the request for evidence in B[2]. The set of intentions in

[15] In the IS representations information arising from the particular move under discussion is represented in bold font.

B[4]: Ok.

$$
\left[\begin{array}{ll}
\text{IS:} & \left[\begin{array}{ll}
\text{PRIVATE:} & \left[\text{BEL: } \{\ \}\right] \\
\text{G:} & \left[\begin{array}{ll}
\text{CSC: } \mathbf{reply\_answer(B, 3, 2)} & \\
\text{OBL: } <> & \\
\text{DH:} & \left[\begin{array}{ll}
\text{DA:} & \left\{\begin{array}{l}
move1 : assert(A, not(helen\_at\_party)), \\
move2 : ask(B, A, ?how(know(A, not(helen\_at\_party)))), \\
move2 : request\_evid(B, 1), \\
move2 : address(B, 1), \\
move3 : assert(A, not(car\_at\_party)), \\
move3 : answer(A, 2), \\
\mathbf{move4 : accept(B, 3)} \\
\mathbf{move4 : address(B, 3)}
\end{array}\right\} \\
\text{LM: } \{\ \} & \\
\text{CONDS: } \left\{\ o : accept\_answer(B, n, 2) \rightarrow o : accept(B, 1)\right\} &
\end{array}\right] \\
\text{SC: } \left\{\ \mathbf{shared\_belief(not(car\_at\_party))}\ \right\} & \\
\text{INT:} & \left[\begin{array}{ll}
\text{I:} & \left\{\begin{array}{l}
i_1 : shared\_belief(not(helen\_at\_party))_A, \\
i_2 : resolved(?how(know(A, not(helen\_at\_party))))_B, \\
i_3 : resolved(?how(know(A, not(helen\_at\_party))))_A, \\
i_4 : shared\_belief(not(car\_at\_party))_A
\end{array}\right\} \\
sat\text{: } \{\mathbf{i_4}\} & \\
drop\text{: } \{\ \} & \\
\gg : \{(i_1,i_2),(i_2,i_3),(i_3,i_4)\} &
\end{array}\right]
\end{array}\right]
\end{array}\right]
\end{array}\right]
$$

FIG. 12. IS following move B[4]

I further contains the intentions associated with those acts. Notice that before the occurrence of B[4] no intention has been satisfied.

Apart from discarding the obligation which had been introduced by A's assertion in A[3] by means of performing an *address* act, the main effect of B's *accept* in B[4] is the satisfaction of the intention i_4 that had been inferred from A[3]. This is achieved in two steps. First, context independent interpretation of the *accept* allows us to infer that the content of A[3] must be considered as shared belief. Then application of the intention downdate rules entails the satisfaction of i_4, the content of which appears in IS.G.SC. As B[4] accepts an assertion which was intended as an answer to B[2], updating the scenario tells us that B will keep the turn and perform an action that expresses the evaluation of the answerhood properties of A[3] with respect to B[2]:

In the context of the *reply_answer* scenario created by B[4], B's assertion B[5] is firstly interpreted as a rejection of A[3] as an answer to B[2] by the context-dependent interpretation rules. The application of CI_UPDATE to the *reject_answerhood* act then results in the obligation that had been triggered by B[2] being reintroduced on top of the previously empty obligation stack. Additionally, the intention that the propositional content of B[5] should count as shared belief is added to I and attached to i_3. Having thus dealt with the argumentation act performed in B[5], the application of CI_UPDATE to the *assert* act adds a further obligation on top of the stack, thus determining the subsequent scenario as one in which A's evaluation of the propositional content of B[5] will take place, as shown in Figure 13.

B[5]: But she could have come by bicycle.

$$
\left[\begin{array}{l}
\text{IS:} \\
\left[\begin{array}{ll}
\text{PRIVATE:} & \left[\text{BEL: } \{\ \}\right] \\
\text{G:} & \left[\begin{array}{ll}
\text{CSC:} & \mathbf{respond\_assert(A, 5)} \\
\text{OBL:} & < \mathbf{address(A, 5)}, \mathbf{answer(A, 2)} > \\
\text{DH:} & \left[\begin{array}{ll}
\text{DA:} & \left\{\begin{array}{l}
move1 : assert(A, not(helen\_at\_party)), \\
move2 : ask(B, A, ?how(know(A, not(helen\_at\_party)))), \\
move2 : request\_evid(B, 1), \\
move2 : address(B, 1), \\
move3 : assert(A, not(car\_at\_party)), \\
move3 : answer(A, 2), \\
move4 : accept(B, 3) \\
move4 : address(B, 3) \\
\mathbf{move5 : assert(B, poss(helen\_cycle))}, \\
\mathbf{move5 : reject\_answerhood(B, 3, 2)}
\end{array}\right\} \\
\text{LM: } \{\ \} \\
\text{CONDS:} & \left\{\ o : accept\_answer(B, n, 2) \rightarrow o : accept(B, 1)\right\}
\end{array}\right] \\
\text{SC:} & \left\{\ shared\_belief(not(car\_at\_party))\ \right\} \\
\text{INT:} & \left[\begin{array}{ll}
\text{I:} & \left\{\begin{array}{l}
i_1 : shared\_belief(not(helen\_at\_party))_A, \\
i_2 : resolved(?how(know(A, not(helen\_at\_party))))_B, \\
i_3 : resolved(?how(know(A, not(helen\_at\_party))))_A, \\
i_4 : shared\_belief(not(car\_at\_party))_A, \\
\mathbf{i_5 : shared\_belief(poss(helen\_cycle))_B}
\end{array}\right\} \\
sat\text{: } \{i_4\} \\
drop\text{: } \{\ \} \\
\gg : \{(i_1,i_2),(i_2,i_3),(i_3,i_4),(\mathbf{i_3}, \mathbf{i_5})\}
\end{array}\right]
\end{array}\right]
\end{array}\right]
\end{array}\right]
$$

FIG. 13. IS following move B[5]

In contrast to B's moves B[4] and B[5], which could be interpreted as the evaluation of the assertive and answerhood properties of A[3] respectively, interpretation of A's reply to B[5], which like B[4] occurs in a *respond_assert* scenario, requires the application of context accommodation rules.

As A[6] does not contain anything which hints at A's evaluation of the propositional content of B[5], we cannot assign an argumentation act to this move and thus have to try to accommodate the context as shown in Figure 14. According to the accommodation rules defined in Figure 11 above, A[6] can be understood as an implicit acceptance of B[5]. Applying CI_UPDATE to the *accept* act then allows us to downdate the obligation to *address* B[5] from OBL as well as to infer the satisfaction of B's intention i_5 that the possibility of Helen going to the party by bicycle become shared belief. After updating the scenario to *reply_question*, A[6] now can be interpreted once more as a move that replies to B's question in B[2]. Notice that after application of context accommodation the dialogue acts performed in A[6] are still kept in IS.G.DH.LM and that context independent update has not yet been applied to the *assert* act:

In the accommodated context *reply_question*, context-dependent interpretation can interpret A[6] as an answer to B's question in B[2]. Applying CI_UPDATE to A's *answer* argumentation act satisfies the obligation to *answer* B[2] which was reintroduced by B[5]. It should be pointed out that the intention which can be inferred from

A[6]: I stayed there until 4am and she didn't show up.

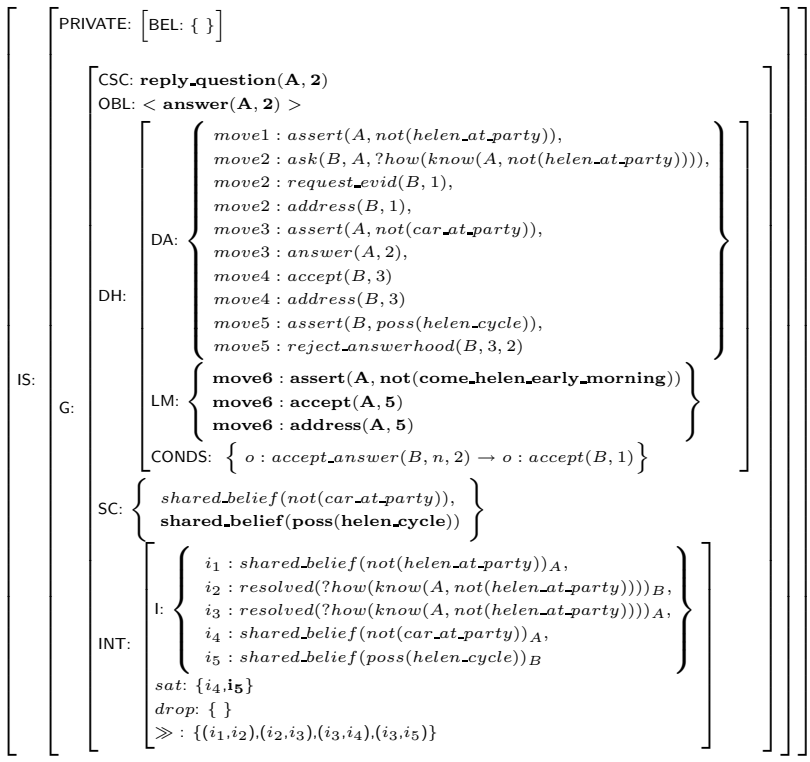

FIG. 14. IS following move A[6]

the *answer* act is already contained in I (i_3), as this is the one which motivated A's first, failed, attempt to answer B[2] in move A[3]. It is at this point that we finally apply context independent updates to the *assert* act in A[6]. This results, firstly, in a new intention i_6 being added to I, where attachment of i_6 to i_3 indicates that any action that contributes to accepting the assertive content of A[6] will also contribute to the acceptance of the DPs' intention that the request for evidence be resolved. On the other hand, the obligation introduction rules for the *assert* act trigger the obligation on B to *address* A[6], and this determines the new scenario as a *respond_assert* in which the turn is assigned to B, as shown in Figure 15.

As the final IS representation in Figure 16 shows, our update algorithm analyses B's final move B[7] as performing a whole range of simultaneous dialogue acts. As it occurs in the scenario created by the assertion in A[6], B's *ok* is first of all interpreted as an acceptance of A[6]. Via CI_UPDATE we then infer the subsequent dropping of the obligation introduced by A[6] as the *accept* constitutes an *address*. The scenario now changes from *respond_assert* to *reply_answer* and no further move is performed by B, so context accommodation has to apply, interpreting B[7] as acceptance of A[6] as an answer which resolves B's request for evidence in B[2]. An antecedent

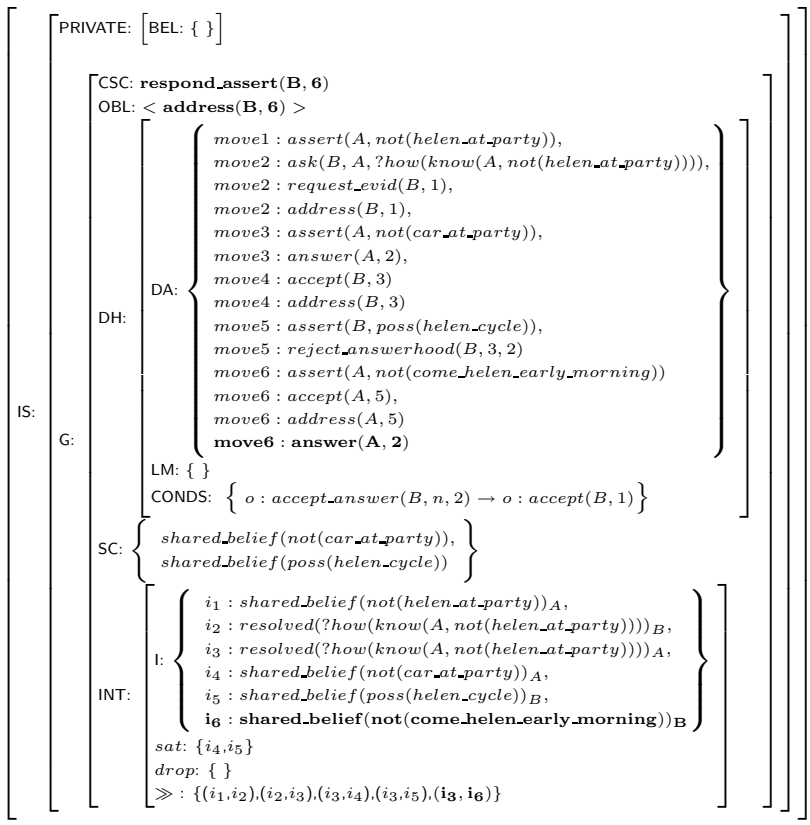

FIG. 15. IS following further updates after move A[6]

for the conditional introduced by B[2] now appears in IS.G.DH.DA, enforcing the interpretation of B[7] as an acceptance and, via CI_UPDATE, as addressing A's initial assertion in A[1].

The intuitive impression that B[7] is a move that results in the successful termination of the dialogue initiated by A[1] is reflected in the IS by the fact that there are no pending obligations after B[7], and also by the satisfaction of all intentions that have arisen in the course of the interaction. The various acceptance acts assigned to B[7] affect the intentional structure in particular: i_6, the equivalent intentions i_3 and i_2, and finally i_1 are satisfied and their respective contents are added to the set of A's and B's commitments. Dialogue control will now be taken over by the DPs' higher-level reasoning, such as the consideration of further private goals or plans.

5 Conclusion

In this paper we have outlined a formal framework for incremental IS updates in a dialogue model which uses discourse obligations as the basic means of dialogue control in subdialogues initiated by questions and assertions. Apart from accounting

B[7]: Ok.

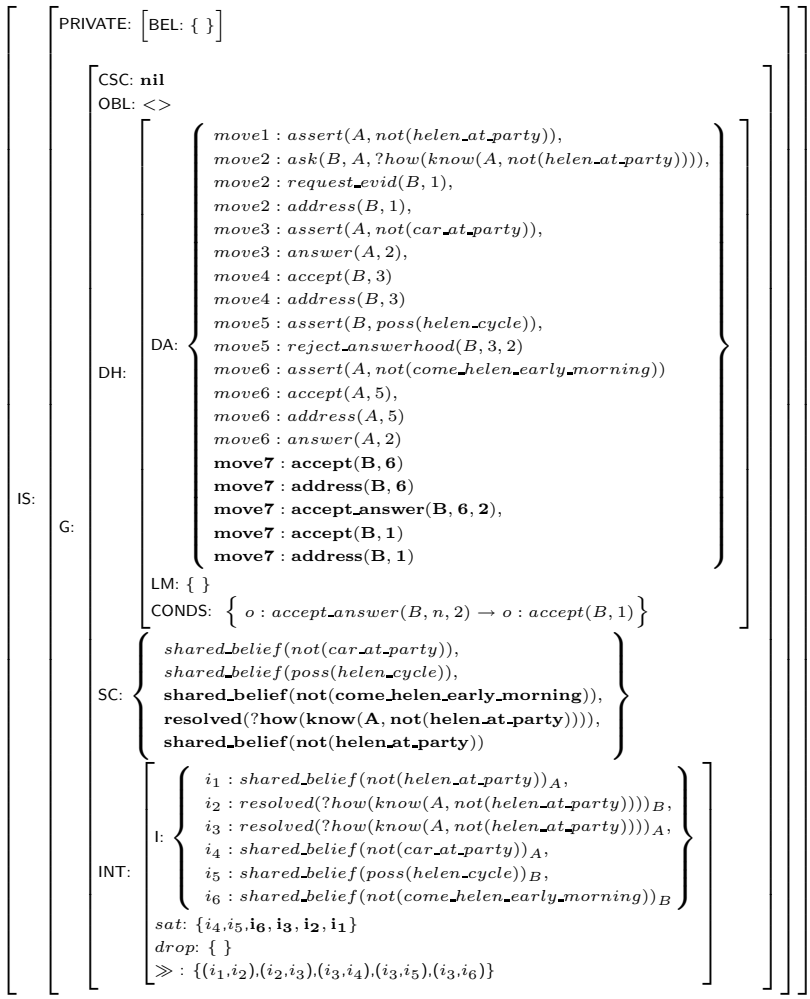

FIG. 16. IS following move B[7]

for the fact that the participants in a dialogue do act even in situations in which their behaviour cannot be explained in terms of intentions ([26]), our definition of IS update scenarios has shown that representing the obligations imposed on the DPs as a stack structure can provide the necessary expressive means for determining characteristic states in the course of a dialogue in which DPs plan their own actions and interpret those of their conversational partners. Our use of discourse obligations therefore can be seen as an alternative to Ginzburg's notion of QUESTION UNDER DISCUSSION as far as the latter's function for expressing dialogue structure is concerned (see [12], [17]).

In addition to this, assigning intentional structure by means of practical inference

rules operating on the dialogue history allows us to reconstruct some commonsense assumptions about the intentional structure of dialogue and the way it is related to the linguistic structure of an interaction. Assuming goals referring to the status of an assertion or question in the course of a conversation as constituents of intentional structure, the rules proposed above account for, for instance, the central aspects of Cohen and Levesque's model of answering as the adoption of an asker's intention (see [7], [18]) and analyse an assertion which is given as an answer to a question as motivated by the askee's intention for the question to be resolved.

Apart from this general account of intentional structure in dialogue, which enables us to model the context dependent aspects of assertions and questions in information-oriented dialogues, we are able to show that the structures generated by our model can be read in terms of CONVERSATIONAL GAMES (for a detailed discussion of this issue see [18]). However, it is not only the structuring aspect of games that can be accounted for in a flexible manner by the use of discourse obligations. As update scenarios correspond to 'states' in a games model, we claim that our approach can in principle integrate probabilistic ranking methods for deciding the likelihood of follow-up moves, thus preserving one of the main attractions that the games model has in the field of practical dialogue systems.

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