The Interpretation of Questions in Dialogue

Alex Lascarides
School of Informatics
University of Edinburgh

alex@inf.ed.ac.uk

Nicholas Asher
IRIT
Université Paul Sabatier

asher@irit.fr

Abstract

We propose a dynamic semantics of questions in dialogue that tracks the public commitments of each dialogue agent, including commitments to issues raised by questions.

1 Introduction

A semantic framework for interpreting dialogue should provide an account of the content that is *mutually accepted* by its participants. The acceptance by one agent of another's contribution crucially involves the theory of what that contribution means; A's acceptance of B's contribution means that the content of B's contribution must be integrated into A's extant commitments.[1] For assertions, traditionally assumed to express a proposition formalised as a set of possible worlds, it was clear how the integration should go: acceptance meant intersecting the newly accepted proposition with the set of worlds representing the content of the agent's prior commitments. Dynamic semantics (e.g., Asher (1989)) refined this picture by replacing intersection with the operation of dynamic update. The way to treat the negative counterpart of acceptance—namely, rejection—is also clear in principle: $A's$ rejection of B's assertion means that the negation of the content of B's contribution should be integrated with the content of A's prior commitments.

However, acceptance and rejection don't just happen with assertions. These speech acts can happen with questions as well. That is, an agent can choose to address the issues raised by the questioner; he can also choose to reject them. The explicit acceptance of a question can be conveyed by providing a direct answer or by an explicit admittance that one doesn't know an answer; explicit rejection by uttering *I won't answer*.

[1] Lascarides and Asher (2009), following (Hamblin, 1987, p.240), argue that public commitment is the appropriate mental attitude of a speaker towards his own dialogue moves and the moves that he accepts. We adopt this standpoint here as well.

Arndt Riester & Torgrim Solstad (eds.):
Proceedings of SuB13, Stuttgart, 000–000.

Agents can also signal acceptance or rejection of questions via implicature, just as they can indicate acceptance or rejection of assertions by implicature, as Lascarides and Asher (2009) show. For instance, compare (1) (from dialogue r053c in the Verbmobil corpus (Wahlster, 2000)) with the excerpt (2) of a press conference given by Mr. Sheehan, the aide to Senator Coleman (see www.youtube.com/watch?v=VySnpLoaUrI).[2]

(1) a. A: Can you meet in the morning?
b. B: How about eight thirty to ten?

(2) a. REPORTER: On a different subject is there a reason that the Senator won't say whether or not someone else bought some suits for him?
b. SHEEHAN: Rachel, the Senator has reported every gift he has ever received.
c. REPORTER: That wasn't my question, Cullen.
d. SHEEHAN: The Senator has reported every gift he has ever received. We are not going to respond to unnamed sources on a blog.
e. REPORTER: So Senator Coleman's friend has not bought these suits for him? Is that correct? [The dialogue continues with Sheehan repeating (2)b to every request for information from the reporters]

In (1), *B* responds to *A*'s question with a question; but *B*'s question, given its content, also implicates that he accepts the issues raised by *A*'s question (i.e., he is indicating his willingness to help answer (1)a). In (2), Sheehan's assertion (2)b is clearly not an answer to the question (2)a, and in (2)c the reporter (correctly) takes it as a refusal to answer. This refusal is not explicit—like uttering *I won't answer* would be—but implicit.

In this paper we propose an account of acceptance and rejection of questions. Standard theories of the semantics of questions (Kartunnen (1977), Groenendijk and Stokhof (1982) or Ginzburg (1995)) are difficult to integrate with an intuitive theory of acceptance and rejection. All of these theories take the content of a question to be its set of answers (they differ on what counts as an answer in context and on whether the set denoted by the question includes only true or both true and false answers). But how can we use such a set of answers to update the commitments of an agent who accepts or refuses a question?

Some theories model acceptance in terms of an agent's commitments to a set of propositions, but it is clear from the way these sets are conceived that the elements in the set are understood intersectively; i.e., the set representation is just another way of formulating the traditional approach to acceptance. This will not work with the semantics of questions in general, and it's easy to see why: the set of answers to a question are often inconsistent with each other. For instance, the semantics of a *yes/no* question like *Did you take the garbage*

[2]Thanks to Chris Potts for bringing this example to our attention.

out? is given in terms of two propositions: You took the garbage out, and you did not take the garbage out. Taking the intersection of these two propositions yields an empty set. Conceivably, if a question denotes only answers that are true at the world of evaluation, one might avoid this absurd result. But it has equally bad consequences for acceptance: it would imply that agents who accept questions are always committed to its true answers; and thus one can't truthfully respond to a *yes/no* question with *I don't know but your question is an interesting one*, since the responding agent is already committed to the true answer (be it positive, or negative). Thus, traditional semantic analyses of questions appear to be incompatible with intuitive accounts of acceptance and rejection.

If the formal semantics of questions is to be made relevant to accounting for the basic phenomena of acceptance and rejection in dialogue, it has to change. That is what we propose to do in this paper. There is additional pressure on the traditional semantics of questions from data on embedded speech acts: Asher (2007) argues that it cannot adequately handle questions embedded within other operators like conditionals—as in *If I buy into this plan, what can I expect my returns to be?* Asher (2007) provides a dynamic, first order adaptation of Groenendijk's (2003) semantics for questions to recursively compute appropriate values for embedded speech acts; the general idea is to use a question's direct, exhaustive answers to form a partition over the input information state and then to lift the dynamic semantics of other operators and quantifiers so as to define them as transitions from an input partition to an output partition. In this paper, we demonstrate that this semantics is also the basis for a uniform account of the acceptance (and rejection) of questions and assertions in dialogue. It achieves this by making the input and output contexts for interpreting propositions and questions of the same type, and so an agent can be simultaneously committed to questions and propositions and also share those commitments with other agents.

We motivate and describe our model in Section 2, and in Section 3 we define the dynamic semantics for questions and show how it makes intuitively compelling predictions about acceptance and rejection.

2 Background

To our knowledge, there is currently no formally precise, adequate account of acceptance (and rejection) of both propositions and questions in dialogue. The Grounding Acts Model (GAM, Traum (1994), Poesio and Traum (1998)) addresses the effects of both questions and assertions on an information state. In Poesio and Traum's (1998) formalisation of GAM, agreement occurs when one agent accepts a prior assertion that's made by another agent. Questions, on the other hand, create an obligation on the interlocutor to respond, but GAM as it stands does not address the issue of predicting when the response conveys, indirectly, that the speaker is prepared to answer the question (as in (1)). So GAM needs to be supplemented to

Turn	A's SDRS	B's SDRS
1	$\pi_{1.1} : K_{\pi_{1.1}}$	$\emptyset$
2	$\pi_{1.1} : K_{\pi_{1.1}}$	$\pi_{2B} : \mathit{Correction}(\pi_{1.1}, \pi_{2.1})$
3	$\pi_{3A} : \mathit{Correction}(\pi_{1.1}, \pi_{3.1}) \wedge \mathit{Acceptance}(\pi_{2.1}, \pi_{3.1})$	$\pi_{2B} : \mathit{Correction}(\pi_{1.1}, \pi_{2.1})$

Table 1: The logical form of dialogue (3).

account for this data.

Asher and Lascarides' (2003) SDRT also addresses updates with questions and assertions. But its traditional semantics for questions makes it fall prey to the problem about acceptance that we described in Section 1. While Ginzburg (1995) provides very detailed predictions for when a question is resolved, his theory does not predict when an agent rejects the question; indeed he observes in Ginzburg (2009) that being a question under discussion is a necessary but not a sufficient condition for both acceptance and rejection of the issues raised by the question.

Lascarides and Asher (2009) argue that Poesio and Traum's (1998) rules for identifying speech acts undergenerate acceptance in many cases and that SDRT from Asher and Lascarides (2003) errs in the opposite direction to GAM by *overgenerating* acceptance. To correct these problems, Lascarides and Asher (2009) propose a logical form for dialogue that tracks each agent's public commitments. They argue that these include commitments to *rhetorical connections* (e.g., *Narration*) among utterances in the dialogue, on the grounds that recognising implicit acceptance and identifying the rhetorical connection that links an agent's utterance to the dialogue context are logically co-dependent. So they propose that each agent's commitments at any given stage in the dialogue be represented as a Segmented Discourse Representation Structure (SDRS): this is a set of *labels* that each represent a unit of discourse, and a function that associates each label with a formula representing the unit's interpretation. These formulae include rhetorical relations among labels.

To see how this framework handles both acceptance and rejection, consider (3), an example where A accepts a denial of his prior assertion:

(3) $\pi_{1.1}$. A: It's raining.
$\pi_{2.1}$. B: No it's not.
$\pi_{3.1}$. A: Oh, you're right (*uttered after looking out the window*).

The logical form of a dialogue turn (where a turn boundary occurs whenever the speaker changes) is a tuple of SDRSs: one for each agent, representing his public commitments. The logical form of dialogue—known as a Dialogue SDRS or DSDRS—is the logical form of each of its turns, yielding Table 1 as the logical form for dialogue (3). For reasons of space, the logical forms of the clauses are omitted from Table 1. We will often gloss the content of a label π as K_π, and use

π_{nd} to label the dialogue segment of turn n with (unique) speaker d, and $\pi_{n.i}$ to label the i^{th} elementary discourse unit that is part of the turn π_{nd}. The glue-logic inference that *Correction*$(\pi_{1.1}, \pi_{3.1})$ is a part of A's commitments in turn 3 arises from the fact that $\pi_{3.1}$ is an *Acceptance* of the corrective move $\pi_{2.1}$ (see Lascarides and Asher (2009)). The SDRSs in a DSDRS share labels because a speaker can perform a relational speech act whose first argument is part of a prior turn (e.g., $\pi_{1.1}$ and $\pi_{2.1}$ are literals in A's SDRS for turn 3 in Table 1). As a special case, it captures the fact that an agent can reveal his commitments (or lack of them) to content that another agent conveyed, even if this is linguistically implicit.

To see how DSDRSs capture facts about acceptance and rejection, let's review how they're are interpreted. Asher and Lascarides (2003) define precisely the *context change potential* (CCP) of an individual SDRS. Since the logical form of a dialogue turn is now a tuple of SDRSs, its CCP is the *product* of the CCPs of the individual SDRSs. In other words, the context of evaluation C_d for interpreting a dialogue turn is a set of dynamic contexts for interpreting SDRSs—one for each agent $a \in D$, where D is the set of dialogue agents. Thus, where C_a^i and C_a^o are respectively an input and output context for evaluating an SDRS:

$$C_d = \{\langle C_a^i, C_a^o \rangle : a \in D\}$$

The semantics of a dialogue turn $T = \{S_a : a \in D\}$ is the product of the CCPs its SDRSs, as shown in (4) (m in $[\![.]\!]_m$ stands for monologue and d in $[\![.]\!]_d$ for dialogue):

(4) $C_d [\![T]\!]_d C'_d$ iff $C'_d = \{\langle C_a^i, C_a^o \rangle \circ [\![S_a]\!]_m : \langle C_a^i, C_a^o \rangle \in C_d, a \in D\}$

And given that a turn represents *all* of each agent's current commitments, the CCP of a DSDRS is that of its last turn. Dialogue entailment is then defined in terms of the entailment relation $\models_m$ afforded by $[\![.]\!]_m$ of SDRSs:

(5) $T \models_d \phi$ iff $\forall a \in D, S_a \models_m \phi$

Thus $\models_d$ defines shared public commitments, and we assume that ϕ is mutually accepted in turn T among D iff $T \models_d \phi$. Similar definitions hold for acceptance among a subgroup $D' \subset D$: i.e., for all $a \in D'$, $S_a \models_m \phi$.

Equation (6) defines the dynamic interpretation of veridical relations (e.g. *Narration*, *Explanation*, *Acceptance*), ensuring that a discourse unit consisting of veridical relations entails its smaller discourse units plus the relations' illocutionary effects $\varphi_{R(\alpha,\beta)}$:

(6) $C^i [\![R(\alpha, \beta)]\!]_m C^o$ iff $C^i [\![K_\alpha \wedge K_\beta \wedge \varphi_{R(\alpha,\beta)}]\!]_m C^o$

(7) $C^i [\![\mathit{Correction}(\alpha, \beta)]\!]_m C^o$ iff $C^i [\![(\neg K_\alpha) \wedge K_\beta \wedge \varphi_{Corr(\alpha,\beta)}]\!]_m C^o$

Meaning postulates then constrain the content $\varphi_{R(\alpha,\beta)}$: e.g., $\varphi_{Explanation(\alpha,\beta)}$ entails K_β is an answer to *Why* K_α*?* Equation (7) is the interpretation of *Correction* and it entails the negation of the denied segment.

Turn	A's SDRS	B's SDRS
1	$\pi_{1A} : K_{\pi_{1.1}}$	$\emptyset$
2	$\pi_{1A} : K_{\pi_{1.1}}$	$\pi_{2B} : \mathit{Q\text{-}Elab}(\pi_{1.1}, \pi_{2.1})$

Table 2: The logical form of (1).

Turn	R's SDRS	S's SDRS
1	$\pi_{1.1} :?K_{\pi_{1.1}}$	$\emptyset$
2	$\pi_{1.1} :?K_{\pi_{1.1}}$	$\pi_{2.1} : K_{\pi_{2.1}}$
3	$\pi_{3A} : \mathit{Commentary}^*(\pi_{2.1}, \pi_{1.1})$	$\pi_{2.1} : K_{\pi_{2.1}}$
4	$\pi_{3A} : \mathit{Commentary}^*(\pi_{2.1}, \pi_{1.1})$	$\pi_{4B} : \mathit{Explanation}^*(\pi_{4.1}, \pi_{4.2})$
5	$\pi_{5A} : \mathit{Result}^*(\pi_{4B}, \pi_{5.1}) \wedge \mathit{Elaboration}(\pi_{5.1}, \pi_{5.2})$	$\pi_{4B} : \mathit{Explanation}^*(\pi_{4.1}, \pi_{4.2})$

Table 3: The logical form of dialogue (2)

These definitions capture intuitions about acceptance and rejection for dialogue (3), given its logical form in Table 1. Assuming that $K_{\pi_{1.1}}$ to $K_{\pi_{2.1}}$ are expressed appropriately, turn 2 in Table 1 entails that A is committed in $K_{\pi_{1.1}}$ while B rejects it (for his commitments entail $\neg K_{\pi_{1.1}}$), a rejection that A then accepts in turn 3. The CCP of Table 1 thus reflects intuitions about changing commitments and agreement. At the end of turn 3 both agents agree that it's not raining, and A has dropped an earlier commitment in favour of an incompatible commitment. The DSDRS is consistent even though A's SDRS for turn 2 is inconsistent with his SDRS for turn 3, and the SDRSs for turn 2 are inconsistent with each other.

This formalism provides logical forms for dialogues involving questions as well, as shown in Tables 2 and 3, the proposed logical forms for dialogues (1) and (2) respectively. Consider Table 2 first. The relation $\mathit{Q\text{-}Elab}(\pi_{1.1}, \pi_{2.1})$—which means that $\pi_{2.1}$ is a question all of whose possible answers elaborate a plan to achieve the goal of $\pi_{1.1}$, which here is for A to know its answer—intuitively implicates a commitment by B to the question $\pi_{1.1}$ posed by A (we'll see later why this doesn't quite work in Asher and Lascarides' (2003) model theory though).

The DSDRS for (2) in Table 3 (R is the reporter and S is Sheehan) contains lots of implicit rejections. Again, we have omitted the logical forms of clauses because of space. The lack of a relation between S's utterance $\pi_{2.1}$ and R's question $\pi_{1.1}$ implicates a rejection by S of the question (although, as we've mentioned, to ensure that this intended interpretation is reflected in the model theory, we must revise the semantics of questions).[3] R's commitments in turn 3 are to

[3]Readers familiar with SDRT may wonder why S's SDRS is not $\pi_{2S} : \mathit{Plan\text{-}Elab}(\pi_{1.1}, \pi_{2.1})$—this would implicate that S accepts R's question, because it entails that $\pi_{2.1}$ elaborates a plan to achieve the intention that prompted it; namely, for R to know an answer. While $K_{\pi_{2.1}}$ is

Commentary$^*(\pi_{2.1}, \pi_{3.1})$—that is, his utterance is a commentary on the fact that S said $\pi_{2.1}$ (rather than a commentary on its content $K_{\pi_{2.1}}$). Thus the semantics of this relation does not entail $K_{\pi_{2.1}}$, indicating R's lack of commitment to it. *Result*$^*(\pi_{4B}, \pi_{5.1})$ in S's SDRS for turn 5 likewise entails that a particular *assertion* π_{4B} was made but not that assertion's content (in contrast to *Result*): it entails that S making the assertions he did leads to the question $\pi_{5.1}$ (which is in effect the earlier question that R asked). So R does not accept the content of S's assertions, just as S doesn't accept the issues raised by the question.

Note that acceptance and rejection in dialogue (2) are implicated but not part of semantic content. This is because anaphoric tests suggest that these acts, while implicated, are *not* a part of what the agents said: the reporter cannot coherently respond to (2)b with *Why?* (meaning "why are you refusing to answer the question?"). SDRT distinguishes what was said from its cognitive effects partly so as to account for these anaphoric effects: antecedents to surface anaphors must be chosen from SDRSs, while cognitive effects are validated within a separate cognitive logic not discussed here (but see Asher and Lascarides (2008)).

However, as we mentioned before, the dynamic interpretation Lascarides and Asher (2009) provide for DSDRSs has a serious defect in its semantics for questions, which undermines the generality of its model of acceptance. We will now remedy this defect.

2.1 Questions

The semantics of SDRSs in Asher and Lascarides (2003), on which the model of dialogue in Lascarides and Asher (2009) is based, incorporates a traditional semantics of questions, according to which the meaning of a question is given by its set of (true) answers (in this it follows Groenendijk and Stokhof (1982) but agrees with Ginzburg (1995) that those answers need not be exhaustive). More formally, the context of evaluation in SDRT is a pair of elements (w, f), where w is a possible world and f is a partial variable assignment function. But the CCP of a question transforms an input state (w, f) into an output state of a different type: a set of dynamic propositions, each proposition being a true answer. In other words, the output state of a question is a set of pairs of world assignment pairs.

While this semantics of questions has a certain appeal when considered in isolation, it is problematic when questions are part of the content of an extended dialogue. This is because the output context of a question cannot be the input context for interpreting a subsequent discourse unit. Therefore, questions cannot be arguments to veridical rhetorical relations, given their CCP in (6). And yet

compatible with the semantics of *Plan-Elab*$(\pi_{1.1}, \pi_{2.1})$, an inference to this relation is blocked by knowledge of S's mental state: namely, R and S mutually know that S, being an aide to the senator, knows the answer. By S not providing an answer when he knows it, R can infer that S does not adopt R's intention for R to know an answer, and thus an inference to the speech act *Plan-Elab* is not validated.

intuitively, the second question in (2)e should be construed as *elaborating* the first question in (2)e (as we've shown in Table 3), since all true answers to one entail a true answer to the other. Asher and Lascarides (2003) provide many more examples where questions can enter into relations that are normally associated with assertions, like *Explanation* and *Narration*.

SDRT as described in Asher and Lascarides (2003) bypasses this problem by introducing a distinct relation $Elaboration_{qq}$ for connecting an 'elaborating' question to the question it elaborates. Semantically, the CCP of $Elaboration_{qq}(\pi_{1.1}, \pi_{2.1})$ makes it a *test* on the input context: in words, the input context (w, f) must be such that $K_{\pi_{1.1}}$ and $K_{\pi_{1.2}}$ are questions, and any true answer to $K_{\pi_{2.1}}$ in (w, f) entails a true answer to $K_{\pi_{1.2}}$ in (w, f). Similar additional relations are introduced for other veridical rhetorical relations—e.g., $Explanation_{qq}$ and $Narration_{pq}$.

But the problems go much deeper than this. The proliferation of non-veridical relations for handling questions is not just an inconvenience; it is a fatal flaw in our proposed model of acceptance. If R's commitments in turn 5 are represented in terms of $Elaboration_{qq}$, then R is not committed even to his own questions, contrary to intuitions. Rather, he is simply committed to the two questions being in a certain semantic relationship. Similarly, consider the relation $Q\text{-}Elab(\pi_{1.1}, \pi_{2.1})$, which forms part of B's SDRS for turn 2 of (1). As we said, this expresses the information that $K_{\pi_{2.1}}$ is a question and any of its possible answers elaborate a plan to achieve the communicative goal behind $K_{\pi_{1.1}}$ (that A know an answer to the question $K_{\pi_{1.1}}$). But out of technical necessity the CCP of *Q-Elab* from Asher and Lascarides (2003) is a test on the input context, and so B's SDRS does not commit him to $K_{\pi_{2.1}}$ or $K_{\pi_{1.1}}$. This undergenerates what's accepted for (1): it makes B committed to the answers of $\pi_{2.1}$ bearing a certain semantic relationship with those of $\pi_{1.1}$, but it fails to commit B to A's question, and therefore also fails to predict that R's responses to S's question in (2) are different in this respect from B's responses to A's in (1).

Ideally, we want a semantics for questions that is compatible with an agent being committed to it. This requires the input and output contexts for questions and for propositions to be of uniform type, allowing both of them to be arguments to veridical rhetorical relations. This would not only solve the problem with acceptance that we have just described, but it would also simplify the inventory of rhetorical relations: a question could be an argument to *Elaboration*, obviating the need for the distinct relation $Elaboration_{qq}$ that comes with similar implicatures to *Elaboration*; similarly for all other veridical relations. Groenendijk's (2003) semantics of questions assumes uniform input and output contexts for both propositions and questions. Asher (2007) generalises this semantics to provide a dynamic treatment of variables and quantifiers so as to preserve SDRT's predictions about anaphora (Groenendijk treats quantifiers statically). This is the semantics that we will adopt here. While the semantic type of the contexts C^i_a and C^o_a for SDRSs will change, the definitions (4) and (5) for interpreting DSDRSs will be unchanged.

3 Formal Syntax and Semantics

Before we refine the formal semantics of questions, we must define the language's syntax. We start with the syntax of so-called SDRS-formulae from which DSDRSs are built (Definition 1 is from Asher and Lascarides (2003)).

Definition 1 The Syntax of SDRS-Formulae

SDRS-formulae are constructed from the following vocabulary:

vocab-1. A classical first order vocabulary, augmented with the modal operator δ that turns formulae into action terms ($\delta\phi$ is the action of bringing it about that ϕ and this is used to represent imperatives); and the operator '?' and λ-terms for representing questions as $?\lambda x_1 \dots \lambda x_n \phi$, each x_i corresponding to a *wh*-element.

vocab-2. labels: π, π_1, π_2, etc.

vocab-3. a set of symbols for rhetorical relations: R, R_1, R_2, etc.

The set $\mathcal{L}$ of well-formed SDRS-formulae is defined as follows:

1. Let $\mathcal{L}_{basic}$ be the set of well-formed formulae that are derived from vocab-1 using the usual syntax rules for first order languages with action terms and questions. Then $\mathcal{L}_{basic} \subseteq \mathcal{L}$.
2. If R is an n-ary discourse relation symbol and $\pi_1, \dots, \pi_n$ are labels, then $R(\pi_1, \cdots, \pi_n) \in \mathcal{L}$.
3. For $\phi, \phi' \in \mathcal{L}, (\phi \wedge \phi'), \neg\phi \in \mathcal{L}$.

Definition 2 reflects the logical forms proposed in Lascarides and Asher (2009) and illustrated in Tables 1 to 3. It maps each dialogue turn and agent into an SDRS: that is, a rooted and well-founded partial order of labels, each one standing for a discourse unit and associated with a representation of its content. For simplicity, we have ignored Asher and Lascarides' (2003) notion of a *last* label in these definitions, since we won't be focussing on anaphora in this paper.

Definition 2 DSDRSs

Let D be a set of dialogue participants. Then a Dialogue SDRS (or DSDRS) is a tuple $\langle n, T, \Pi, \mathcal{F} \rangle$, where:

- $n \in \mathcal{N}$ is a natural number (intuitively, $j \leq n$ is the j^{th} turn in the dialogue);
- Π is a set of labels;
- $\mathcal{F}$ is a function from Π to the SDRS-formulae $\mathcal{L}$;

- T is a mapping from $[1, n]$ to a function from D to SDRSs drawn from Π and $\mathcal{F}$. That is, if $T(j)(a) = \langle \Pi_j^a, \mathcal{F}_j^a \rangle$ where $j \in [1, n]$ and $a \in D$, then $\Pi_j^a \subseteq \Pi$ and $\mathcal{F}_j^a =_{def} \mathcal{F} \upharpoonright \Pi_j^a$ (that is, $\mathcal{F}_j^a$ is $\mathcal{F}$ restricted to Π_j^a). Furthermore, let $\pi \succ_j^a \pi'$ iff π' is a literal in $\mathcal{F}_j^a(\pi)$ or a literal in $F_j^a(\pi'')$ where $\pi \succ_j^a \pi''$. Then $\succ_j^a$ is a well-founded partial order with a unique root.

There are many notational variants for DSDRSs—Table 1 is a notational variant of the DSDRS (8) for example:

(8) $\langle 2, T, \{\pi_{2B}, \pi_{3A}, \pi_{1.1}, \pi_{1.2}, \pi_{2.1}, \pi_{3.1}\}, F\rangle$, where:

- $F(\pi_{1.1}) = K_{\pi_{1.1}}$, $F(\pi_{2.1}) = K_{\pi_{2.1}}$, $F(\pi_{3.1}) = K_{\pi_{3.1}}$
  $F(\pi_{2B}) = \mathit{Correction}(\pi_{1.1}, \pi_{2.1})$
  $F(\pi_{2K}) = \mathit{Correction}(\pi_{1.1}, \pi_{3.1}) \wedge \mathit{Acceptance}(\pi_{2.1}, \pi_{3.1})$
- $T(1) = \{(A, \langle\{\pi_{1.1}\}, F_1\rangle), (B, \emptyset)\}$, where $F_1 = F \upharpoonright \{\pi_{1.1}\}$
- $T(2) = \{(A, \langle\{\pi_{1.1}\}, F_1\rangle), (B, \langle\{\pi_{2B}, \pi_{1.1}, \pi_{2.1}\}, F_2\rangle)\}$
  where $F_2 = F \upharpoonright \{\pi_{2B}, \pi_{1.1}, \pi_{2.1}\}$
- $T(3) = \{(A, \langle\{\pi_{3A}, \pi_{1.1}, \pi_{2.1}, \pi_{3.1}\}, F_3\rangle), (B, \langle\{\pi_{2B}, \pi_{1.1}, \pi_{2.1}\}, F_2\rangle)\}$
  where $F_3 = F \upharpoonright \{\pi_{3A}, \pi_{1.1}, \pi_{2.1}, \pi_{3.1}\}$

Definition 2 allows label sharing across speakers and turns but the content assigned to a label is unique: $\forall \pi \in \Pi_j^{a_1} \cap \Pi_k^{a_2}$, $j, k \in [1, n]$, $a_1, a_2 \in D$, $\mathcal{F}_j^{a_1}(\pi) = \mathcal{F}_k^{a_2}(\pi)$. A situation where a_1 and a_2 interpret π differently won't correspond to a situation where π is assigned distinct contents in distinct SDRSs within the *same* DSDRS. Rather, it corresponds to a situation where a_1 and a_2 each build different DSDRSs (although we won't explore misunderstandings further here).

With the syntax of the formal language in place, let's define its semantics. As we explained in Section 2.1, the semantics $[\![.]\!]_d$ of DSDRSs requires the input and output contexts for propositions, questions and requests to be the same. We now adapt the semantics from Asher and Lascarides (2003) to meet this criterion. We start with a few illustrative clauses of the distributive, non-eliminative CCP for $\mathcal{L}_{basic}$ from Asher and Lascarides (2003), which we refer to here as $[\![.]\!]_\delta$. Our new semantics $[\![.]\!]_m$ of SDRSs will be defined in terms of $[\![.]\!]_\delta$. Both $[\![.]\!]_\delta$ and $[\![.]\!]_m$ are defined with respect to a model $M = \langle \Delta, W, I\rangle$, where Δ is a set of individuals, W is a set of possible worlds and I is an interpretation function that maps n-place predicates into sets of n-tuples from Δ.

The CCP $[\![.]\!]_\delta$ from Asher and Lascarides (2003) treats all formulae save $\exists x$, conjunctions, imperatives and questions as tests on the input context. For instance: $(w, f)[\![P(x)]\!]_\delta(w', g)$ iff $(w, f) = (w', g)$ and $f(x) \in I(P)$; and $(w, f)[\![\neg\phi]\!]_\delta(w', g)$ iff $(w, f) = (w', g)$ and there is no (w'', k) such that $(w, f)[\![\phi]\!]_\delta(w'', k)$. Conjunction is interpreted as dynamic succession: $(w, f)[\![\phi \wedge \psi]\!]_\delta(w', g)$ iff $(w, f)[\![\phi]\!]_\delta \circ [\![\psi]\!]_\delta(w', g)$. Questions, as we have already stated, transform an input context (w, f) into a set of propositions that are its true (non-exhaustive) answers (see Asher and Lascarides (2003) for details). The formula $\exists x$ updates the input variable assignment function: $(w, f)[\![\exists x]\!]_\delta(w', g)$ iff $dom(g) = dom(f) \cup \{x\}$ and $f \subseteq g$ (i.e., $\forall y \in dom(f)$, $f(y) = g(y)$). Note that $\exists x\phi$ is syntactic sugar for $\exists x \wedge \phi$. Action terms, on the other hand, update the world: $(w, f)[\![\delta\phi]\!]_\delta(w', g)$ iff $(w', f)[\![\phi]\!]_\delta(w', g)$.

Following Asher (2007), we will 'lift' the distributive semantics $[\![.]\!]_\delta$ to a collective semantics $[\![.]\!]_m$ so that it can incorporate the collective semantics to questions proposed in Groenendijk (2003). This strategy results in a uniform type of input and output context for all formulae. Asher demonstrates that this allows questions to be embedded in conditionals (e.g., *If you're serious, what's his name?*). Here, we demonstrate that it also properly accounts for their rhetorical role in dialogue, including their role in acceptance.

For Groenendijk, a question *partitions* the input information state, which in turn consists of all the world assignment pairs that have not been ruled out by prior assertions. Each equivalence class in the output partition represents a different possible answer to the question. Thus the input and output contexts C_m are always a subset of $(W \times F)^2$, where W is the set of possible worlds and F is the set of partial variable assignment functions, and $\langle (w, f), (w', g)\rangle \in C_m$ means that (w, f) and (w', g) are in the same equivalence class. One can intuitively interpret the equivalence class in terms of the agent's attitudes: if $\langle (w, f), (w', g)\rangle \in C_m$, then the agent 'doesn't care' about the different interpretations to formulae that these world-assignment pairs define. If, on the other hand, (w, f) and (w', g) are in different classes of C_m then the agent does care—he is committed to a question whose true answers are different in (w, f) vs. (w', g). Assertions that are subsequent to a question may then remove all but one equivalence class from the partition that's created by the question; if so, the question is answered.

Informally, then, our new dynamic semantics $[\![.]\!]_m$ for SDRS-formulae is as follows. For those formulae ϕ where $[\![.]\!]_\delta$ imposes a test on the input context—so ϕ is *not* of the form $\exists x$, $\psi \wedge \chi$, $\delta\psi$ or $?\psi$—$[\![\phi]\!]_m$ has an entirely eliminative and distributive semantics. In other words, any element $\langle (w, f), (w', g)\rangle$ from the input context C will survive as an element of the output context C' iff $(w, f)[\![\phi]\!]_\delta(w, f)$ and $(w', g)[\![\phi]\!]_\delta(w', g)$. $\exists x$, on the other hand, *changes* the input assignment functions f and g, by extending them to be defined for x. $\delta\phi$ changes the input worlds. Conjunction is dynamic succession, as before. And following Groenendijk (2003), questions will *refine* the input partition by eliminating pairs $\langle (w, f), (w', g)\rangle \in C$, according to whether (w, f) and (w', g) define different possible answers. Whether they do this or not is determined by whether the $[\![.]\!]_\delta$-semantics of the question transforms (w, f) and (w, g) into the same set of true answers, or not. These principles for defining $[\![.]\!]_m$ lead to Definition 3—we will see shortly how this semantics is extended to SDRS-formulae that feature rhetorical relations.

Definition 3 The Semantics $[\![.]\!]_m$ of $\mathcal{L}_{basic}$

Let $M = \langle D, W, , I\rangle$ be a model, and let $C, C' \subseteq (W \times F)^2$. Then:

(i) $C[\![P(x_1,\ldots,x_n)]\!]_m^M C'$ iff
$$C' = \{\langle (w,f),(w',g)\rangle \in C: \; (w,f)[\![P(x_1,\ldots x_n)]\!]_\delta^M(w,f) \text{ and } (w',g)[\![P(x_1,\ldots,x_n)]\!]_\delta^M(w',g)\}$$

(ii) $C[\![\exists x]\!]_m^M C'$ iff $C' = \{\langle (w,f'),(w',g')\rangle : \; \langle (w,f),(w',g)\rangle \in C, (w,f)[\![\exists x]\!]_\delta^M(w,f') \text{ and } (w',g)[\![\exists x]\!]_\delta^M(w',g')\}$

(iii) $C[\![\phi \wedge \psi]\!]_m^M C'$ iff $C[\![\phi]\!]_m^M \circ [\![\psi]\!]_m^M C'$.

(iv) $C[\![\neg\phi]\!]_m^M C'$ iff $C' = \{\langle (w,f),(w',g)\rangle \in C: \; (w,f)[\![\neg\phi]\!]_\delta^M(w,f) \text{ and } (w',g)[\![\neg\phi]\!]_\delta^M(w',g)\}$

(v) $C[\![\delta\phi]\!]_m^M C'$ iff $C' = \{\langle (w^o,f'),(w'^o,g')\rangle : \; \langle (w,f),(w',g)\rangle \in C \text{ and } (w,f)[\![\delta\phi]\!]_\delta^M(w^o,f') \text{ and } (w',g)[\![\delta\phi]\!]_\delta^M(w'^o,g')\}$

(vi) $C[\![?\lambda x_1\ldots x_n\phi]\!]_m^M C'$ iff
$C' = \{\langle (w,f),(w',g)\rangle \in C:$
$\forall f'$ st $dom(f') = dom(f) \cup \{x_1,\ldots,x_n\}$ and $f \subseteq f'$,
$\exists g'$ st $dom(g') = dom(g) \cup \{x_1,\ldots x_n\}$ and $g \subseteq g'$, and
$f'(x_i) = g'(x_i), 1 \leq i \leq n$ and
$\exists (w'',k),(w''',l)$ st
$(w,f')[\![\phi]\!]_\delta^M(w'',k) \leftrightarrow (w',g')[\![\phi]\!]_\delta^M(w''',l)$
and conversely:
$\forall g'$ st $dom(g') = dom(g) \cup \{x_1,\ldots x_n\}$ and $g \subseteq g'$,
$\exists f'$ st $dom(f') = dom(f) \cup \{x_1,\ldots,x_n\}$ and $f \subseteq f'$, and
$f'(x_i) = g'(x_i), 1 \leq i \leq n$ and
$\exists (w'',k),(w''',l)$ st
$(w,f')[\![\phi]\!]_\delta^M(w'',k) \leftrightarrow (w',g')[\![\phi]\!]_\delta^M(w''',l)\}$

The CCPs (6) and (7) of rhetorical relations lift immediately to these new contexts of evaluation; so $C^i, C^o \subseteq (W \times F)^2$ in these definitions. But we can now take advantage of the uniform contexts of evaluation for propositions and questions. As promised in Section 2.1, rhetorical connections among questions can be simplified. Unlike the $[\![.]\!]_\delta$-semantics from Asher and Lascarides (2003), questions in the $[\![.]\!]_m$-semantics can be arguments to veridical relations such as *Elaboration*. So the SDRS representing the turn (2)e, as shown in Table 3, invokes an *Elaboration* on labels for questions. Thus the reporter is committed to the issues raised by both questions, and the second question can be paraphrased in this context as *So is it correct that Senator Coleman's friend has not bought these suits for him?*

Further examples of rhetorical relations involving questions from Asher and Lascarides (2003) are *QAP* (Question Answer Pair) and *Q-Elab* mentioned earlier. We start with the semantics of *QAP*. The semantics of questions in Definition 3, following Groenendijk's (2003), assumes that a direct answer to a question is an *exhaustive* answer. But in reality, the demands on answerhood are not so stringent during dialogue interpretation (Ginzburg, 1995): a question can be resolved to the questioner's satisfaction without the answer being exhaustive. We reflect this in our semantics of *QAP*—we make it match the constraints on specificity for answerhood that we assumed for this relation in our earlier work.

Technically, we achieve this by introducing a predicate symbol *Answer* between a question and a proposition. $Answer(q,p)$ is a test on the input context, but the test may be passed even if p is not an exhaustive answer (and so fails to exclude all but one class from the partition created by q). In essence, as in Asher and Lascarides (2003), p must identify *de re* values for q's *wh*-elements, or entail that no such elements exist. So it is a stronger constraint on answerhood than partial answerhood but not as strong a constraint as exhaustive answerhood. For instance, $Answer(q,p)$ will be true when q is *Who talked?* and p is *Mary talked*: this is not an exhaustive answer (people other than Mary may have talked) and accordingly fails to eliminate all but one class from the partition created by q. The formal definition of the predicate *Answer* is as follows:

- $C[\![Answer(?\lambda x_1,\ldots,x_n\phi,p)]\!]_m C'$ iff
  1 $C = C'$; and
  2 $\forall C''$ such that $C[\![?\lambda x_1,\ldots,x_n\phi]\!]_m C''$, there is a C''' such that $C''[\![p]\!]_m C'''$ and either
    - $\exists a_1,\ldots a_n \in \Delta$ such that for all $(w,f) \in \bigcup\bigcup C'''$, $\exists(w',g)$ st $(w, f\frac{a_1}{x_1}\ldots\frac{a_n}{x_n})[\![\phi]\!]_\delta(w',g)$ or
    - $\forall a_1,\ldots a_n \in \Delta$ and for all $(w,f) \in \bigcup\bigcup C'''$, $\neg\exists(w',g)$ st $(w, f\frac{a_1}{x_1}\ldots\frac{a_n}{x_n})[\![\phi]\!]_\delta(w',g)$

The semantics of *QAP* is then defined in terms of *Answer*, to reflect the intuition that non-exhaustive answers can play a rhetorical role in a dialogue of being a sufficiently specific answer:

$$C[\![QAP(\alpha,\beta)]\!]_m C' \text{ iff } C[\![K_\alpha \wedge Answer(K_\alpha,K_\beta) \wedge K_\beta]\!]_m C'$$

In words, $QAP(\alpha,\beta)$ partitions its input state C into one that distinguishes among the possible exhaustive answers to the question K_α, the resulting partition satisfies the test imposed by $Answer(K_\alpha,K_\beta)$—in other words, updating C with K_β would yield an output state that identifies *de re* values to K_α's *wh*-elements, or it identifies that there no such values exist—and finally the context is updated by K_β, and hence the output context C' has resolved (in the rhetorical sense, if not in the literal sense) the question K_α. The original definition of $QAP(\alpha,\beta)$ from Asher and Lascarides (2003) was not veridical on α; now it is, reflecting the fact that answering a question entails acceptance of the issues raised by the question.

Similarly, whereas the original definition of *Q-Elab* from Asher and Lascarides (2003) was non-veridical our revised definition makes it veridical. In other words, its CCP is defined by (6), with meaning postulates on $\varphi_{Q\text{-}Elab(\alpha,\beta)}$ constraining K_β so that it helps achieve the intentions behind α (formal details are omitted here, but see Asher and Lascarides (2003)). We can similarly define a univocal semantics for *Result*, *Result**, *Elaboration*, *Commentary* and *Commentary**, regardless of whether their terms are questions or assertions.

We have now defined the $[\![.]\!]_m$-semantics for all SDRS-formulae. The semantics of an SDRS is the semantics of the content of its unique root label. In other words, for an SDRS S with root label π_0, $C[\![S]\!]_m C'$ iff $C[\![K_{\pi_0}]\!]_m C'$. The semantics $[\![.]\!]_d$ of a DSDRS is then defined in terms of $[\![.]\!]_m$ as described in Section 2: the CCP of a dialogue turn is given in (4); the entailment relation it engenders in (5); and the CCP of an entire DSDRS is that of its last turn.

The illocutionary contributions of speech acts are encoded in the semantics of DSDRSs, as a part of the agents' commitments. And thus our definition of acceptance as joint entailment on those commitments enables implicit acceptance. With our new semantics of SDRSs, we can now make the right predictions about acceptance and rejection of questions, as well as acceptance and rejection of assertions. For instance, with the logical form in Table 2 for dialogue (1), our revised semantics of *Q-Elab* as a veridical relation ensures that B accepts A's question (1)a. In contrast, S does not accept R's questions in dialogue (2), given its logical form in Table 3; nor does R accept S's assertions.

4 Conclusion

This paper presents a dynamic model theory for questions that fully supports a theory of acceptance and rejection for questions and assertions. Following GAM (Traum, 1994), it models acceptance as shared public commitment. However, unlike any prior formally precise theory of dialogue of which we are aware, it is able to represent implicit acceptance, and it also analyses commitments to questions and mutual acceptance of the issues raised by questions.

A crucial ingredient in our account was the use of relational speech acts, and the logical relationships among their semantics. By 'lifting' the distributive dynamic semantics from Asher and Lascarides (2003) to a collective semantics in the style of Groenendijk (2003), we were able to maintain a uniform model of acceptance regardless of whether the speakers utter indicatives or interrogatives.

Acknowledgements. This work has benefited from comments and feedback from Julia Hirschberg, Colin Matheson, Ron Petrick, Chris Potts, Mark Steedman, Matthew Stone, David Traum and Lyn Walker and from the participants at Sigdial 2008, Londial 2008 and SuB13. Any errors that remain are our own.

References

N. Asher. Discourse representation theory and belief dynamics. In A. Fuhrmann and M. Morreau, editor, *The Logic of Theory Change*, pages 282–321, Springer, 1989.

N. Asher. Dynamic discourse semantics for embedded speech acts. In S. Tsohatzidis, editor, *John Searle's Philosophy of Language*, pages 211–244. CUP, 2007.

N. Asher and A. Lascarides. *Logics of Conversation*. CUP, 2003.

N. Asher and A. Lascarides. Commitments, beliefs and intentions in dialogue. In *Proceedings of Londial*, pages 35–42, 2008.

J. Ginzburg. Resolving questions part i. *Linguistics and Philosophy*, 18(5):459–527, 1995.

J. Ginzburg. *Semantics and Conversation*. CSLI Publications, 2009.

J. Groenendijk. Questions and answers: Semantics and logic. In *Proceedings of the 2nd CologNET-ElsET Symposium. Questions and Answers: Theoretical and Applied Perspectives*, pages 16–23, 2003.

J. Groenendijk and M. Stokhof. Semantic analysis of wh-complements. *Linguistics and Philosophy*, 5(2):175–233, 1982.

C. Hamblin. *Imperatives*. Blackwells, 1987.

L. Karttunen. Syntax and semantics of questions. *Linguistics and Philosophy*, 1(1):3–44, 1977.

A. Lascarides and N. Asher. Agreement, disputes and commitments in dialogue. to appear in *Journal of Semantics* volume 26, 2009.

M. Poesio and D. Traum. Towards an axiomatisation of dialogue acts. In *Proceedings of the Twendial*. 1998.

H. Sacks, E. A. Schegloff, and G. Jefferson. A simplest systematics for the organization of turn-taking in conversation. *Language*, 50(4):696–735, 1974.

D. Traum. *A Computational Theory of Grounding in Natural Language Conversation*. PhD thesis, University of Rochester, 1994.

W. Wahlster, editor. *Verbmobil: Foundations of Speech-to-Speech Translation*. Springer, 2000.

M. Walker. Inferring acceptance and rejection in dialogue by default rules of inference. *Language and Speech*, 39(2), 1996.