Discourse Relations and Relevance Implicatures: A Case Study

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Abstract. In this paper, we discuss dependencies between rhetorical discourse structure and relevance implicatures. We follow [3] and infer relevance implicatures from the assumption that an answer provides optimal information for solving an explicitly or implicitly given decision problem of the inquirer. Such a decision problem can be identified with a question raised in the conversation. Background questions not only depend on explicit questions under discussion but may also be raised by rhetorical relations such as Concession or Contrast. In this paper, we are especially concerned with implicatures of *embedded* questions. We show by some examples that determining the rhetorical relation that connects two text spans and setting up a pragmatic model that explains the implicatures of embedded sentences interact with each other.

Key words: discourse relations, relevance implicatures, game theoretic pragmatics, SDRT

1 Introduction

In recent pragmatic research van Rooij's idea [11, 12] to consider pragmatic phenomena as decision problems has turned out to be very fruitful. These decision problems are introduced by explicit or implicit questions of the addressee in a dialogue. The utterance of the speaker is then interpreted as an answer to this question. This approach is especially successful for relevance implicatures and was developed most notably in game theoretic models [11, 7, 3]. We adopt these proposals for implicatures in monologic discourses (instead of dialogues) by assuming the discourse segments to be answers to implicit questions in the background.

The fact that direct answers give rise to implicatures that depend on contextual information about preferences can be seen in examples like (1):

(1) Peter: I have to buy wine for our dinner banquette. I get into trouble with our secretary if I spend too much money on it. We still have some Italian wine. Where can I buy French wine?
Bob: At the Wine Centre.
+> Peter can buy French wine at a low price at the Wine Centre.

The root question in (1) makes no reference to the price of wine. Nevertheless, the contextually given objective of buying wine at a low price has an impact on

the implicature of the answer. These objectives are provided by the linguistic context which stands in a BACKGROUND relation to the question. Interestingly, the same phenomenon can be observed for *embedded* questions:

(2) Peter, the office assistant, was sent to buy French wine for an evening dinner.
- **a)** In the afternoon Ann tells Bob that Peter went shopping but returned without wine. Bob gets very angry about it.
  Ann: "Maybe, it was not his fault."
  Bob: "Oh, Peter knows where he can buy French wine."
- **b)** In the afternoon Ann tells Bob that Peter bought some French wine but it was obviously completely overpriced. Bob gets very angry about it.
  Ann: "Maybe, it was not his fault."
  Bob: "Oh, Peter knows where he can buy French wine."

The sentence of interest containing the embedded question is always "*Peter knows where he can buy French wine.*" In (2a), we only get the interpretation that Peter knows *some* wine shop. In (2b), "Peter, knows where he can buy French wine" must be interpreted such that he knows a cheap place where he can buy it. We informally explain these examples along the following line: In each example, Bob's utterance must be connected to Ann's previous assertion by a rhetorical relation. This relation can be identified as COUNTEREVIDENCE, see [1]. In order to satisfy the conditions for COUNTEREVIDENCE, Bob's assertion must provide evidence that Peter is to blame for his actions. He is to blame for them if he knew an action that would have achieved a better result than the one he actually chose. In (2b), this is the case if he knew how to satisfy the additional objectives of buying cheap wine, i.e. if he knew an answer to the root question '*Where can I buy French wine?*' which also answers the questions for the additional objectives.

These examples show that embedded relevance implicatures depend on structural rhetorical information as well as on Gricean reasoning. Naturally, the question arises how the two aspects are related to each other. Asher and Lascarides [1] explicate Grice's maxim of relation as discourse coherence. This means that for Asher & Lascarides a new text segment is *relevant* to a given segment if, and only if it can be connected by rhetorical relations to it. Hence, there is no need for an additional level of Gricean reasoning except for constructing rhetorical relations. In this context, they discuss a classical example of Grice:

(3) Anne: Smith doesn't seem to have a girl friend. (A)
Bob: He's been paying lots of visits to New York lately. (B)
+> Smith possibly has a girl friend in New York. (R)

The standard explanation starts out with the assumption that the speaker Bob is cooperative and follows the Gricean maxims. Hence, Bob's utterance must satisfy the maxim of relation (Relevance). Bob's answer can only be relevant if the implicature that '*Smith possibly has a girl friend in New York*' is true.

In contrast, the explanation proposed by [1, Ch. 1.2.6] makes no reference to relevance except for rhetorical relations. Anne may reason as follows: (1) Bob's

utterance B must be connected to her utterance A by a rhetorical relation; (2) there are two possible relations connecting Bob's utterance to Anne's: COUNTEREVIDENCE and EVIDENCE; which one can be inferred from prosodic properties; let us assume that the pitch is at *New York*; then the connecting relation is COUNTEREVIDENCE; (3) COUNTEREVIDENCE implies that B must render $\neg A$ more plausible than A; (4) B is evidence for $\neg A$ if one assumes that Smith visits New York because he has a girl friend there. This explains the implicature with reference only to prosodic and semantic information. It involves no reasoning about intentions and Gricean maxims. As Asher & Lascarides argue, this reasoning is cognitively less costly than the standard Gricean reasoning. Similarly, if discourse coherence defined by rhetorical connectedness captures all of Grice maxim of relation, then they have to maintain that rhetorical reasoning alone suffice for explaining the examples in (1) and (2). This raises the issue of whether or not Gricean reasoning apart from rhetorical reasoning is at all necessary for calculating conversational implicatures.

In Section 2, we approach the relation between structural rhetorical information and Gricean reasoning by considering a complex example (4) involving a CONCESSION relation and an embedded question which gives rise to a relevance implicature. The example is such that the sentence containing the embedded question can be connected by two mutually exclusive rhetorical relations to the previous text. This *ambiguity* can be resolved only if the implicature of the embedded question is known. This shows that rhetorical information alone is not sufficient for explaining the example. We will see that calculating the connecting rhetorical relation and setting up the pragmatic model that explains the implicatures must be done simultaneously.

The analysis of the core example is framed in Asher & Lascarides's *Segmented Discourse Representation Theory* (SDRT). In Section 2, for a start we will assume that we already have an explanation for embedded relevance implicatures. This gap will be closed in Section 4. In examples like (1), answers and their implicatures are dependent on multiple contextual objectives. These examples can be handled by the game theoretic framework introduced in [2], which is based on multi–attribute utility theory [8]. In Section 2, we apply this framework to modelling the implicatures of embedded *questions*. This provides the explanations for the examples in (2).

As our analysis in Section 2 will show, a crucial role will be played by a question implicitly raised by the CONCESSION relation. We argue that this question is neither accounted for by rhetorical discourse theories like SDRT, nor by Gricean theories, hence, pointing to a third parameter of discourse interpretation.

2 The Core Example Analysed

In this section we analyse our core example:

(4) *S says in conversation with H who is involved in the organisation of the companies dinner banquette.*: (π_1) In a meeting, it was decided to buy some

caviar for the dinner banquette, (π_2) although it was argued that it is prohibitively expensive to buy it from a catering service. (π_3) The manager said that (π_4) our secretary knows where to buy caviar. (π_5) He ordered you to take care of it.

There are two readings for S's statement. In the first reading, π_3 with the embedded clause π_4 which contains an embedded question is attached to the previous segment by NARRATION. In this case, the manager makes his utterance after the meeting and he provides by it additional information for carrying out the meeting's decision. Hence, π_4 = *that our secretary knows where to buy caviar* is connected by relation PLAN-ELABORATION to π_1. The final sentence π_5 is added to make PLAN-ELABORATION even more plausible. In the second reading, π_3 is attached to the previous segment by ELABORATION, and the manager makes his utterance during the meeting. By his utterance he provides a counterargument to π_2, hence it is connected to π_2 by COUNTEREVIDENCE. The example is such that both readings are plausible with the second reading preferred.

According to [1], NARRATION is the default relation connecting discourse segments. Hence there have to be special reasons for overriding this default to arrive at the second reading. There is no overt indicator for contrast, like *but*. Moreover, and this is the main problem, the literal meaning of π_3 provides no obvious counter–argument against the argument that caviar is excessively expensive. Hence, it has to be explained how π_3 can communicate information which *explains* the meeting's decision.

Before presenting the SDRT analysis, we provide an informal outline of the reasoning that leads to the preferred reading. The discourse relation CONCESSION between π_1 and π_2 raises the background question *why it was decided to buy caviar although it is prohibitively expensive*. If the discourse relation connecting π_1 and π_3 was NARRATION, then this question would remain unanswered. We assume that this background question makes the hearer prefer an interpretation of π_3 which answers it. This is the case if π_3 is connected to the previous segment by ELABORATION, and to π_2 by COUNTEREVIDENCE. For ELABORATION to hold, the two events described by π_1 and π_3 must overlap. From this, it follows that the manager made his statement during the meeting.

It remains to show how COUNTEREVIDENCE can hold between π_3 and π_2. Examples like (1) illustrate that an implicature of an answer can depend on contextually given objectives. From π_2 follows that one of the objectives is to achieve a lower price than expected at the catering services. We assume that the sentence *that our secretary knows where to buy caviar* means that the secretary is an expert, who is able to provide an optimal answer to the root question *where to buy caviar*. An answer is optimal given the additional objective of a lower price, if it not only answers the question *where* it is possible to buy caviar, but also where it is possible to buy it at a low price. This explains why π_3 can be connected to π_2 by COUNTEREVIDENCE.[1]

[1] Note, that our example could be explained along the same lines if the embedding verb *know* was replaced by another factive embedding verb such as *told us*. We would like to thank the anonymous reviewer who pointed this out.

We will provide a model which explains the embedded relevance implicature, and we will also show why π_3 implicates that there exists a caviar shop where one can buy caviar at low cost. It is important to us to emphasis that neither SDRT nor Gricean reasoning alone can explain this example. In particular, Gricean reasoning provides just the *preconditions* for constructing a COUNTEREVIDENCE relation. Both readings the NARRATION / PLAN-ELABORATION and the ELABORATION / COUNTEREVIDENCE reading are still available. What in fact tips the balance in favour of the second reading is the question raised by the CONCESSION relation. This is a new parameter which is not accounted for in SDRT or the optimal answer model of implicature.

2.1 Analysis of rhetorical relations

In the following, we analyse the example in more detail. Figure 1 shows the *segmented discourse representation structure*, SDRS, for the segment consisting of the first two sentences π_1 and π_2. The first sub–SDRS for π_1 says that there

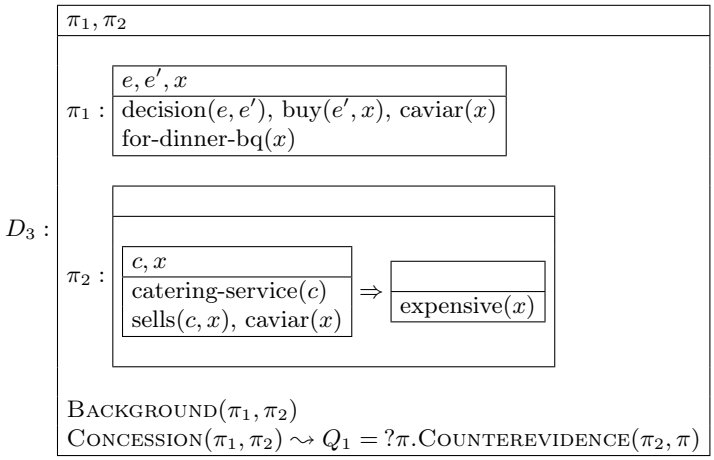


Fig. 1. The SDRS for '(π_1) In a meeting, it was decided to buy some caviar for the dinner banquette, (π_2) although it was argued that it is prohibitively expensive to buy it from a catering service.'

are events e and e' and an object x of caviar, such that e is the decision to do e', and e' the buying of x for the dinner banquette. The sub–SDRS for π_2 says that for all catering services all caviar is expensive. π_2 contains information against the background of which the decision in e was made. At the same time, the addressee is informed that it was raised as a counter argument against the decision. Hence, π_2 can be related by two rhetorical relations, BACKGROUND and CONCESSION, to π_1. The CONCESSION relation raises the question why the decision was made although there were arguments against it. This is indicated

in the last line of the SDRS by '$\rightsquigarrow Q_1 = ?\pi.\textsc{Counterevidence}(\pi_2, \pi)$'. Q_1 asks for a segment π which can be connected to π_2 by Counterevidence, hence for information devaluating the argument raised in π_2.

The update of D_3 with π_3 and its embedded question in π_4 leads in a first step to the SDRS D_4 in Figure 2 with the rhetorical relations R and R' connecting π_3 and π_4 to the previous segments still unresolved. As pointed out in our

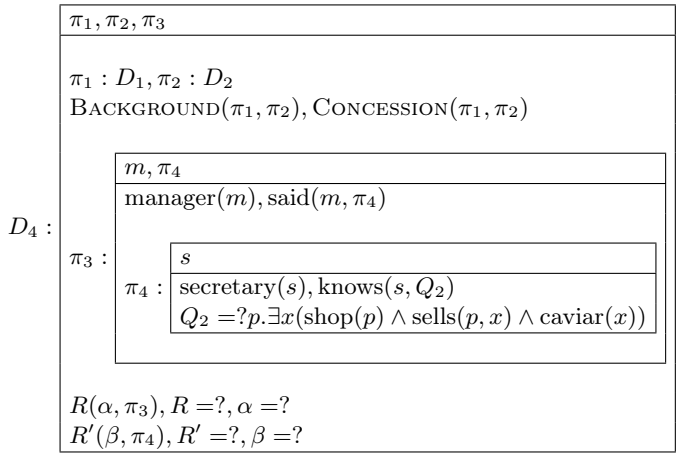


Fig. 2. Underspecified SDRS after '(π_3) The manager said that (π_4) our secretary knows where to buy caviar.'

discussion of Example (4), there are at least two possibilities for the rhetorical relations R and R'. The first possibility is the SDRT default of connecting π_3 to π_1 by Narration. π_4 would then elaborate on the plan of buying caviar. We can assume that the addressee can accommodate that the topic of the meeting was the question $Q_2 = ?p.\exists x(\text{shop}(p) \wedge \text{sells}(p, x) \wedge \text{caviar}(x))$. This question is identical to the question to which the secretary is claimed to know an answer in π_4. This should provide even more reason to relate π_4 to π_1. As we have seen before, discourse relations are not unique in SDRT. For example, π_4 also provides background information for the decision reported in π_1. Hence, it would also be connected to π_1 by Background. It could also be argued that π_4 is not bound anaphorically to π_1 but cataphorically to π_5. We omit these complications as they are not essential to our argument, and focus on the following possibilities:

$$D_5 : \begin{array}{|l|}\hline \ldots \\ \hline \ldots \\ R(\alpha, \pi_3), R = \textsc{Narration}, \alpha = \pi_1 \\ R'(\beta, \pi_4), R' = \textsc{Plan-Elaboration}, \beta = \pi_1 \\ \hline \end{array} \tag{2.1}$$

$$D_6 : \begin{array}{|l|}\hline \ldots \\ \hline \ldots \\ R(\alpha, \pi_3), R = \textsc{Elaboration}, \alpha = \pi_1 \\ R'(\beta, \pi_4), R' = \textsc{Counterevidence}, \beta = \pi_2 \\ \hline \end{array} \tag{2.2}$$

The problem, as mentioned above, is to explain why the ELABORATION / COUNTEREVIDENCE reading is available. The literal content of π_3 would not justify it. It is here where Gricean reasoning enters. The decision to buy caviar reported in π_1, raises the issue $Q_2 = ?p.\exists x(\text{shop}(p) \wedge \text{sells}(p, x) \wedge \text{caviar}(x))$ from whom to buy caviar. Furthermore, CONCESSION(π_1, π_2) also makes clear that the objective of buying cheap caviar must be added to this issue, hence, leading to the question $Q_3 = ?p.\exists x(\text{shop}(p) \wedge \text{sells}(p, x) \wedge \text{caviar}(x) \wedge \textit{cheap}(x))$. We call the questions Q_1, Q_2, and Q_3, which have been raised in this discourse, the *questions under discussion*. The SDRS for the ELABORATION / COUNTEREVIDENCE reading with all the questions under discussion is shown in Figure 3.

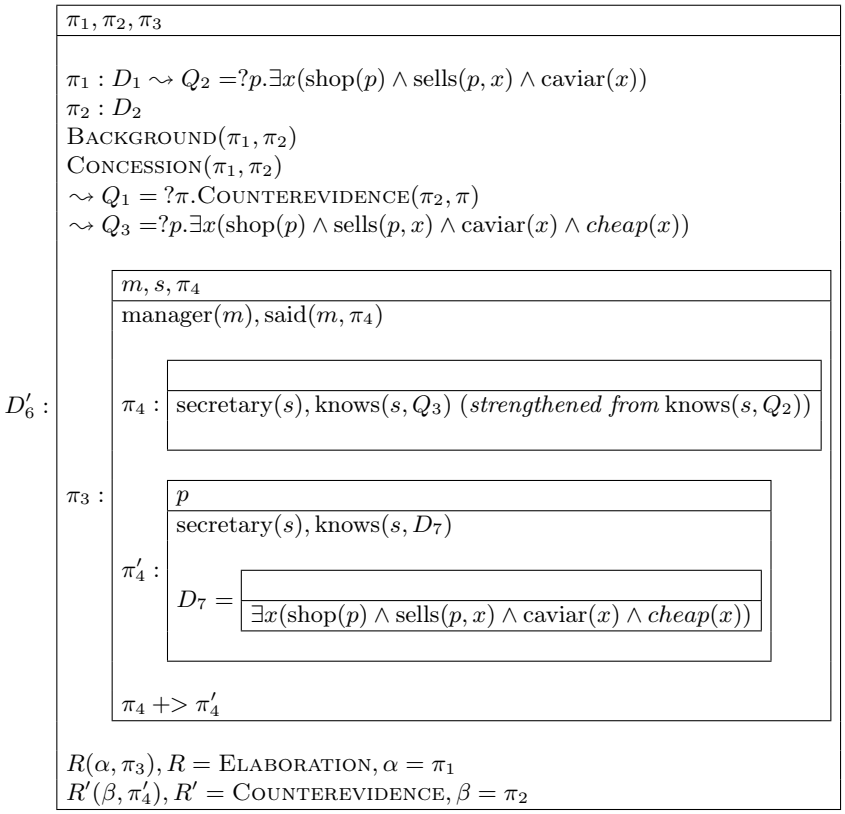


Fig. 3. The SDRS for the preferred reading of (4) with questions under discussion and relevance implicature.

As we have seen in (2), objectives stated in the background can also be added to an *embedded* question. Hence, we assume that in the sub–SDRS for π_4 $\text{knows}(s, Q_2)$ must be strengthened to $\text{knows}(s, Q_3)$ and that $\text{knows}(s, Q_3)$

means that the secretary is an expert who is able to provide an optimal answer to the root question Q_3. As we will see in the next section, this means that the secretary knows a shop which sells caviar at a low price, i.e. (π'_4) holds which says that there exists a shop p such that the secretary knows $\exists w(\text{shop}(p) \wedge \text{sells}(p, w) \wedge \text{caviar}(w) \wedge \textit{cheap}(w))$. As we will also see in the next section, π'_4 is an implicature of π_4. We write $\pi_4 +\!\!> \pi'_4$ for π_4 *implicates* π'_4. This information is also shown in the SDRS in Figure 3. π'_4 provides the counter argument against the argument stated in π_2. This means, the relation COUNTEREVIDENCE holds not between π_2 and π_4 but between π_2 and the implicature π'_4.

What we have established so far are the preconditions for the ELABORATION / COUNTEREVIDENCE reading. Now the question arises why is that the preferred reading and not the NARRATION / PLAN-ELABORATION reading? For that we look at the joint purpose of the talk exchange, which is provided by the question $Q_1 = ?\pi.\text{COUNTEREVIDENCE}(\pi_2, \pi)$, which is automatically raised by the CONCESSION relation. With π'_4 the SDRS for the ELABORATION / COUNTEREVIDENCE reading provides an answer to Q_1; the NARRATION / PLAN-ELABORATION reading would leave it unanswered. This tips the balance. But note: that Q_1 plays this role is entailed neither by SDRT, nor by Gricean pragmatics. It is not a discourse relation, or abstract topic on its own.

Let us briefly sum up. We have seen that SDRT would favour the NARRATION / PLAN-ELABORATION reading. Gricean reasoning was necessary for explaining why the preferred ELABORATION / COUNTEREVIDENCE interpretation is at all available. Decisive is the question raised by CONCESSION. This raising is neither explained by SDRT nor Gricean reasoning. The latter finding suggests that *questions under discussion* may provide a third parameter for discourse interpretation which is not subsumed under the theory of rhetorical structure or conversational implicatures.

2.2 Reasoning about preferences

In the analysis of the core example (4), we made a number of assumptions about Gricean inferences which remain to be justified:

1. The CONCESSION relation entails that the price of caviar is an issue.
2. That the secretary is an expert who knows an answer to the question $Q_3 =$ '*Which shop sells caviar at a low price?*' entails that there exists a shop p such that the secretary knows that p sells caviar at a low price.

Before spelling out some of the details, we provide an intuitive outline of the reasoning that justifies these claims. We start with the first claim. Let c be any catering service. Let $\textit{Good}_1(c)$ be the predicate that says that ordering caviar from c is *good* if, and only if c sells caviar; and let $\textit{Good}_2(c)$ be the predicate that says that ordering caviar from c is *good* if, and only if c sells caviar at a low price. We assume that the outcome of an act of ordering caviar from c is evaluated with 0 or 1. It is evaluated with 1 exactly if it is good to order it from c. This leads to the following table:

Ω	sells-caviar(c)	cheap(c)	$Good_1(c)$	$Good_2(c)$	neutr. alt.
w_1	+	+	1	1	ε
w_2	+	−	1	0	ε
w_3	−	+	0	0	ε
w_4	−	−	0	0	ε

The *neutral alternative* is an alternative act to ordering caviar from c. For example, it may be the act of buying salmon for the dinner banquette. We assume that it has a fixed payoff between 0 and 1. This has the effect that if the catering service does not satisfy the relevant *Good* predicate, then the neutral alternative would be preferred. For a detailed justification of the set up of this model we refer to [2].

Why does CONCESSION(π_1, π_2) imply that $Good_2$ is the correct representation of the meeting's preferences? We assume that a CONCESSION relation of the form '*We decided to do a although* π_2' holds in the context of a decision problem, if learning the conceded fact π_2 would normally induce the decision maker not to choose the act a. If $Good_1$ were the relevant predicate, then learning that it is expensive to buy caviar from c would not be a reason not to order it from c. Hence, the relevant predicate must be $Good_2$. If the meeting learns that they are in state w_2, i.e. that it is expensive to order caviar from c, then this entails that it is better to decide for the neutral alternative.

The fact that $Good_2$ is the correct representation of the meetings preferences entails that the decision to buy caviar can only be *optimal* if a shop p can be found for which $Good_2(p)$ holds. The existence of such a shop does not follow from CONCESSION(π_1, π_2); it likewise does not follow from the fact that the secretary knows an optimal answer to the question where caviar can be bought at a low price because the optimal answer may be *nowhere*. We will argue that the existence of such a shop is accommodated when connecting the implicature π_4' of the manager's utterance with COUNTEREVIDENCE to π_2. This can again be seen from the previous table, with p instead of c. If w_1 is the true state of the world, then an answer can only be optimal if it directs the hearer to order caviar from p. It follows that an expert who knows an optimal answer must know that the true state is w_1. If one of the worlds w_2, w_3, or w_4 is the actual world, then an optimal answer must direct the hearer to choose the neutral alternative. In this case an expert must know that the actual world is in $\{w_2, w_3, w_4\}$, and therefore that there is no shop p which satisfies $Good_2$.

We can summarise the argument of the last paragraph as follows: to be an expert who knows an answer to the question $Q_3 = ?p.(\text{shop}(p) \wedge Good_2(p))$, i.e. $\text{knows}(s, Q_3)$, implies

$$\exists p\, Good_2(p) \Leftrightarrow \exists p\, \text{knows}(s, Good(p)). \tag{2.3}$$

From this, we can infer that COUNTEREVIDENCE(π_2, π_4) can only hold if there exists a shop p for which $Good_2(p)$ holds. If it is not known whether $\exists p Good_2(p)$, then learning that the secretary is an expert knowing an answer would not remove any of the possible worlds $w_1, \ldots, w_4$, and hence, if the arguments for not buying caviar were stronger before learning π_4, they would still be stronger

after learning π_4. If $\exists p\, Good_2(p)$ is accommodated however, then learning π_4 would provide a means to find a shop where cheap caviar can be ordered.

This heightens the burden carried by the question implicitly raised by the CONCESSION relation. It not only has to override the default interpretation NARRATION, and force the strengthening of knows(s, Q_2) to knows(s, Q_3), see Figure 3, but it also has to trigger the accommodation of the existence of a shop with cheap caviar. These considerations point to a quite powerful role of these implicitly raised questions under discussion in discourse interpretation.

Our explanation may raise concerns about the logical relations between *questions*, *answers*, and *contextual objectives* which enter into the definition of *decision problems* which in turn define *optimal* answers. In our model, these concepts are connected to each another by the *Good*–predicate which represents the preferences of the decision maker. The questions which appear in the DRSes, e.g. in Figure 3, are syntactic objects. As these questions do not immediately enter the truth conditions of the DRS, we don't need to commit ourselves to any semantic theory of questions. Questions enter the truth conditions only via the decision problems which they define. An answer is always an answer to a decision problem. This seems to be at odds with common usage. But this problem disappears once we see that a decision problem defined by a *Good*–predicate can be identified with the question $?d.Good(d)$. The answer to this question is in general a *mention-some* answer, cf. [12].

In (2) and in our core example (4), the question Q for which our expert is said to know the answer is defined by a predicate A_1. Hence, Q has the form $?d.A_1(d)$. If in the background no other contextual objective is given, then the question gives rise to the decision problem defined by the predicate $Good(d) :\Leftrightarrow A_1(d)$. However, in all our examples the decision problem is sensitive to a contextually given additional objective A_2. It enters the *Good* predicate of the decision problem as an additional conjunct. Thereby the original question is in fact strengthened to a question of the form $?d.A_1(d) \wedge A_2(d)$, i.e. to $?d.Good(d) :\Leftrightarrow ?d.A_1(d) \wedge A_2(d)$.

Contextual objectives can strengthen root questions as well as embedded questions. If our model is correct, then the meaning of a clause $knows(s, Q_2)$ as in π_4 of (4) has to be calculated by considering the whole decision problem with all contextually relevant objectives. This makes the interpretation of $knows(s, Q_2)$ context dependent. The knowledge attributed to s is the knowledge of an optimal answer to the strengthened decision problem / question. We will see in the next section how to calculate optimal answers.

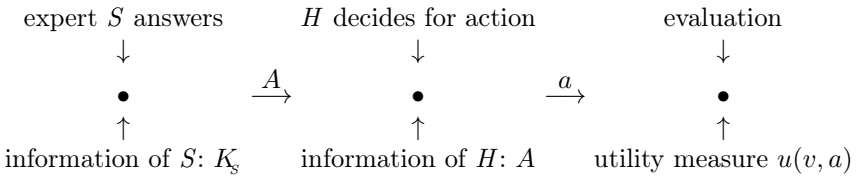
3 The Optimal–Answer Model

Grice [6, p. 26] characterised conversation as a *cooperative effort*. Our contributions are not isolated sentences but normally subordinated to a joint purpose. For example, in the Out-of-Petrol Example (5), the joint purpose is to solve the decision problem of where to go o get petrol [6]:

(5) A is standing next to an obviously immobilized car and is approached by B, after which the following exchange takes place: A: *I am out of patrol.* B: *There is a garage round the corner.* +> The garage is open.

In our examples, questioning and answering are subordinated to a decision problem in which the inquirer has to make a choice between a given set of actions. His choice of action depends on his preferences regarding their outcomes and his knowledge about the world. The answer helps the inquirer in making his choice. The quality of an answer depends on the action to which it will lead. In the Out-of-Petrol example, the actions are the acts of going to a certain place and look for petrol there; in Example (1) they are the acts of buying French wine from a wine shop; and in our core example (4) they are the acts of ordering caviar from a certain shop. The answer is optimal if it induces the inquirer to choose an optimal action.

The speaker S's task is to provide information that is optimally suited to support inquirer H in his decision problem. Hence, we find two successive decision problems, in which the first problem is S's problem to choose an answers. The utility of the answer depends on how it influences H's final choice:



We assume that S is fully cooperative and wants to maximise H's final success; i.e., S's payoff, is identical with H's. This is our representation of Grice's *Cooperative Principle*. S has to choose an answer that induces H to choose an action that maximises their common payoff. For the purposes of our paper, we can restrict our considerations to very simple models. They consist of the inquirer's decision problem and the answering expert's expectations about the world. They incorporate the *Cooperative Principle*, the maxim of *Quality*, and a method for finding optimal strategies which replaces the maxims of *Quantity* and *Relevance*. We ignore the maxim of *Manner*.

A decision problem consists of a set Ω of the possible states of the world, the decision maker's expectations about the world represented by a probability distribution P over Ω , a set of actions $\mathcal{A}$ he can choose from, and his preferences regarding their outcomes. We only consider finite Ω. An agent's preferences regarding outcomes of actions are represented by a real–valued function over action–world pairs. We collect these elements in the following structure: A *decision problem* is a tuple $\langle \Omega, P, \mathcal{A}, u \rangle$ such that (Ω, P) is a finite probability space, $\mathcal{A}$ a finite, non–empty set and $u : \mathcal{A} \times \Omega \to \mathbb{R}$ a function. $\mathcal{A}$ is called the *action* set, and its elements *actions*; u is called a *payoff* or *utility* function. We assume further that $P(v) > 0$ for all $v \in \Omega$.

In the following, a decision problem $\langle \Omega, P, \mathcal{A}, u \rangle$ represents the inquirer's situation before receiving information from an answering expert. We will assume that this problem is common knowledge. For modelling the questioning and

answering situation, we have to add a representation of the answering expert's information state. We identify it with a set K_S of possible worlds:

Definition 1 *A structure* $\langle \Omega, P, K_S, \mathcal{A}, u \rangle$ *is a* support problem *if* $\langle \Omega, P, \mathcal{A}, u \rangle$ *is a decision problem and* $\emptyset \neq K_S \subseteq \Omega$.

How is a support problem solved? It is assumed that rational agents maximise their expected utilities, i.e. the hearer will choose the action which yields the highest average payoff given his information, and the speaker will choose the answer which will induce the hearer to choose actions with maximal expected payoffs as defined from the speaker's perspective. This means, the hearer will choose an action a_A such that $\sum_{w \in A} P(w)\, u(w, a_A)$ becomes maximal, and the speaker will choose A such that $\sum_{w \in K_S} P(w)\, u(w, a_A)$ becomes maximal.

Until now, we have represented the cooperative principle and the principle of maximising utility. We add the maxim of *Quality*. We call an answer A *admissible* if S believes A to be *true*, i.e. if $K_S \subseteq A$. The maxim of Quality is represented by the assumption that the expert S does only give admissible answers. We call an answer *optimal* if it is admissible, and if it induces the hearer to choose actions with maximal expected payoff as defined from the speaker's perspective.

An implicature of an utterance is a proposition which is implied by the assumption that the speaker is cooperative and observes the conversational maxims. More precisely, Grice linked implicatures to what the hearer learns from the utterance about the speaker's knowledge. The answering expert knows a proposition I in a situation σ iff $K_S \subseteq I$. Hence, the inquirer knows that the speaker believed that I when making his utterance A, iff the speaker believes that I in all epistemically possible support problems for which A is an optimal answer. In this case we write $A +\!> I$, i.e. '*the utterance of* A *implicates that* I. For the purposes of this paper, we can restrict considerations to support problems for which the speaker is a real expert, i.e. a person who knows the actual world. If he is an expert, we can show the following Lemma 2, adapted from [2], which provides a very simple criterion for calculating implicatures. The criterion depends on the set $O(a)$ of all worlds in which an action a is optimal:

$$O(a) := \{w \in \Omega \mid \forall b \in \mathcal{A}\, u(w, a) \geq u(w, b)\}. \tag{3.4}$$

This leads to the following lemma:

Lemma 2 *Let* $\langle \Omega, P, \mathcal{A}, u \rangle$ *be a given decision problem, and* $\mathcal{S}$ *the set of support problems* $\{\langle \Omega, P, K_S, \mathcal{A}, u \rangle \mid \exists v \in \Omega\, K_S = \{v\}\}$. *Let* A *be an optimal answer for some* $\sigma \in \mathcal{S}$ *such that for all* σ *in which it is an optimal answer there exists a unique action* a_A *with maximal expected payoff. Let* $I \subseteq \Omega$. *Then, it holds that:*

$$A +\!> I \;\; \textit{iff} \;\; A \cap O(a_A) \subseteq I. \tag{3.5}$$

A proof can be found in [2].

It remains to be said how to set up a concrete model of a specific example like the Out-of-Petrol example, or our introductory example (1). We consider

situations in which the hearer has to choose from a number of domain object $d \in D$ for which his preferences are defined by the conjunction of two predicates $A_1(d)$ and $A_2(d)$. In [2], principles for setting up normal optimal answer models were formulated. For the case of preferences defined by two predicates, these principles simplify to the following set of rules:

1. *Possible worlds.* There is a possible world for each combination of truth values of the predicates $A_1(d)$ and $A_2(d)$.
2. *Insufficient reason.* All elements of Ω are equally probable: $\forall v\, P(v) = |\Omega|^{-1}$.
3. *Utilities.* Choosing d can assume exactly two utility values: it becomes 1 if $A_1(d) \wedge A_2(d)$ holds, and it becomes 0 if $A_1(d) \wedge A_2(d)$ does not hold. We write $Good(d)$ iff $A_1(d) \wedge A_2(d)$.
4. *Neutral alternative.* There exists a neutral alternative action l which has identical payoff in all possible worlds. l is the hearer's choice before learning new information; but if there is a *good* domain object, then l is not an optimal act.
5. *Expert assumption.* The speaker is an expert.

Together, these default rules define models which only vary with respect to the payoff of the neutral alternative.

4 Questions and their implicatures

In this section, we apply the optimal answer model to our introductory examples, and show that the assumptions stated in the core example follow.

In the case of the Out-of-Petrol example, let d be the place of the garage, $G(d)$ the proposition that says that d is a petrol station, and $H(d)$ the proposition that says that d is open. Then, we arrive at the following model:

Ω	$G(d)$	$H(d)$	go-to-d	search
w_1	+	+	1	ε
w_2	+	−	0	ε
w_3	−	+	0	ε
w_4	−	−	0	ε

We assume that P and ε are such that, after learning that d is a garage, the inquirer thinks that the expected utility of going to that garage is higher than doing a random search in town. We see that $a_{G(d)} =$ go-to-d, and $O(\text{go-to-}d) = \{w_1\} \subseteq H(d)$. Hence, by Lemma 2, it follows that $G(d) +\!> H(d)$.

The model of the introductory example is identical, except that $G(d)$ has to be replaced by a predicate which says that d sells French wine, and $H(d)$ by a predicate which says that it sells products at a low price.

These examples show that the interpretation of answers is sensitive to the contextually given attributes and the properties of the utility function. The actual meaning can be inferred from the fact that the answer must be optimal. In (2), we have seen examples which show that contextual attributes, the properties

of the utility function, and optimality of answers also determines the interpretation of *embedded* questions. This fact can easily be explained if we assume that knowing an answer means being an expert who knows an optimal answer. In terms of the optimal answer model, this means, we must put the person knowing the answer in the role of the expert.

Let us now turn to the core example (4). We have seen how to calculate optimal answers, and the implications of being an expert knowing an optimal answer. It remains to show why the strengthened version of π_4 '*Our secretary knows where to buy cheap caviar*' implicates that there exists a shop p of which the secretary knows that it sells cheap caviar π_4'. Informally, we explained it by the fact that the question $Q_1 = ?\pi.\textsc{Counterevidence}(\pi_2, \pi)$ raised by the Concession relation leads to the accommodation of the existence of such a shop. We now can make this step more precise. The fact that Concession *automatically* raises question Q_1 can be interpreted such that the addressee automatically asks this question, hence, putting him into the position of the inquirer with respect to Q_1. In line with this reasoning, subsequent discourse segments can be interpreted as optimal answers to this question. The decision which the addressee has to make is which argument did in the meeting succeed over the counter-argument conceded in π_2 with the neutral alternative of leaving the question open. As the meeting has decided to buy caviar, there must have been a reason. If the addressee learns that the actual state is in $\{w_2, w_3, w_4\}$, then no such reason is offered. Hence, the addressee can infer that w_1 is the true state of affairs. This shows that under the assumption that the sentence π_4 is an optimal answer to Q_1, it follows that there is a shop p such that the secretary knows $\pi_4' = \exists w(\text{shop}(p) \wedge \text{sells}(p, w) \wedge \text{caviar}(w) \wedge \mathit{cheap}(w))$. By definition, this means that $\pi_4 +\!> \pi_4'$. This closes the last gap in our analysis.

5 Conclusion

Our case study has shown that rhetorical structure on its own is not sufficient for determining the interpretation of discourse. It provides a small set of relations which can connect discourse segments, and thereby greatly restricts the set of possible interpretations, but in general it does not restrict it enough to make interpretation unique. As our core example illustrates, embedded relevance implicatures depend on structural rhetorical information as well as on Gricean reasoning. Hence, Asher & Lascarides's [1] thesis that discourse coherence defined by rhetorical connectedness makes Gricean reasoning superfluous cannot be maintained. Gricean reasoning is necessary for calculating conversational implicatures.

We considered an example (4) in which a sentence containing an embedded question can be connected to the previous text by two mutually exclusive rhetorical relations (cf. 2.1 and 2.2 in Section 2). Reasoning about preferences and speaker's intentions is necessary to resolve this ambiguity. A proponent of a purely rhetorical approach had to show that this reasoning could be avoided.

We used normal optimal answer models [2] for Gricean reasoning and inferring relevance implicature. Our example has shown that calculating the connecting rhetorical relation and defining the pragmatic model explaining the implicatures must be done simultaneously. In order to set up a normal optimal answer model, the common goal of the talk exchange must be given in the form of a decision problem. The decision problem can be defined by a question together with other contextually given objectives. We have seen that such a question may be implicitly provided by rhetorical relations. In our core example, the question raised by the CONCESSION relation played a crucial role. This question cannot be explained by Gricean reasoning, as this presupposes a common purpose which only exists after the question has been raised. Likewise, this question is not accounted for by rhetorical discourse theories. This suggests that the raising and resolving of discourse structuring questions is a further layer in discourse organisation. This provides a connection from our case study to discourse theories that are based on a question-answer-relation, i.e. Question-Under-Discussion models [10, 5, 4]. The question how this connection has to be spelled out, must be left to future research.

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