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Mental state recognition and communicative effects

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Speech acts in natural language dialogues can be regarded as intentional acts performed by a dialogue participant to influence the relevant aspects of the mental state of a recipient. In this paper, a framework is discussed for deriving the beliefs and intentions of a speaker from a certain speech act. To this end, the notion of a speech act is replaced by the formal notion of a communicative act. A communicative act is expressed in terms of prosodic and textual features of the utterance and connected by means of default rules of the conditions that must be fulfilled by a speaker in order to perform the act felicitously. To indicate preferences among sets of conditions, hierarchic default rules were introduced. The conditions are expressed in terms of beliefs and intentions of the speaker and the hearer and may be compared with Searle's felicity conditions on speech acts. It is argued, though, that some of the conditions can be derived from a formalization of general principles of rational behaviour in dialogues. Communicative effects were computed on the basis of the consequences of the observed communicative act and the actual circumstances of the act.

1. Introduction

In Levinson (1983) it is argued that a promising approach for speech act theory would be one in which speech acts are characterized in terms of their context-changing effects. In this approach (Isard, 1975; Stalnaker, 1978; Gazdar, 1981; Bunt, 1989) context is limited to mental states of the participants in terms of wants, desires, beliefs, expectations, etc. and a speech act (or illocutionary act)¹ is taken as a function that changes one context into another. For instance, an order can cause, under the appropriate circumstances, a change in the hearer's

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¹ The terms *illocutionary act* and *speech act* are interchangeable in this paper.

mental state from one where he or she is not required to bring about a certain state of affairs into one in which he is required to do so.

The idea of context change is formalized in Bunt (1989), where, in line with Gazdar (1981) and Searle (1969), a *communicative function*² (*CF*) is applied to a (propositional) content (*c*), yielding a communicative act: $CF(c) = CA$. Successful communication is accomplished if the felicity conditions of the act are recognized by the recipient and if the conditions become mutual belief. In other words, what the utterance communicates is that its felicity conditions are fulfilled.

Although the context-change approach to speech acts seems to offer an attractive formal treatment of mental state changes of dialogue participants, there are still many problems to be solved, such as the updating of the contexts or the speech act recognition. Here, we will concentrate on the recognition problem or, more precisely, on how relevant parts of the speaker's mental state can be communicated by means of the linguistic features that are used in the utterance. Previous studies (Allen and Perrault, 1980; Kautz, 1990; Pollack, 1990) have been concentrating on the recognition of the speaker's plan, in terms of goals and future actions, but are hardly based on linguistic knowledge. In this paper it is not our aim to give a plan-based analysis of the recognition of the goals of the speaker; instead, we will concentrate on the identification of the speech act or, more explicitly, the identification of a speaker's intended information transfer from the linguistic features and the actual circumstances of the utterance.

In the framework that will be presented, in line with Cohen and Levesque (1990a) we will avoid illocutionary labelling and attempt to determine the mental states directly from the linguistic features of the utterance. For reasons described below, we will assume that no one-to-relation exists between mental states and linguistic features and that contextual dependencies should be incorporated to determine the function of the utterance.

The terms 'speech act' or 'illocutionary act' will be replaced by the more formal notion of *communicative act*. A *communicative function*, i.e. the formal counterpart of an illocutionary force, will be expressed in terms of observable features of the utterance and only those features will be taken into account that contribute to revealing particular attitudes of the speaker, in terms of *beliefs* and *intentions*, towards a certain proposition. For that purpose, a framework will be introduced to represent beliefs, intentions and actions of an agent. Communicative acts will be considered as 'normal' actions, i.e. intentionally performed to change certain aspects of the world.

The framework is amply inspired by Perrault's (1990) work on an application of default logic in speech act theory. In particular, default rules will be used to include contextual dependency and to reason without complete

² Bunt uses the term *communicative function* and *communicative action* instead of *illocutionary force* and *illocutionary action*, respectively.

knowledge. Perrault's framework has been adapted in three ways. First, we have included a way to represent relevant pragmatic properties of the sentence in the performed communicative act, such as particles and prosodics. Second, we have worked out a hierarchy of default rules to include a priority mechanism for the interpretation of the communicative act. Finally, following Bunt (1989), the consequences of the default rules are explicitly represented as the felicity conditions that should be fulfilled to perform the communicative act. It is claimed, however, that some of the felicity conditions, such as introduced by Searle (1969), can be left out, since they follow from the belief and intention axioms that are introduced in the next chapter. Moreover, it should be noted that we slightly deviate from Perrault's axioms on intention and that we have adopted a notion more similar to Allwood (1976), Bratman (1990) and Cohen and Levesque (1990b).

1.1. *Recognition of the speech act*

An obvious linguistic candidate that discloses the illocutionary force of a speech act is the appearance of an explicit performative in co-occurrence with the adverb 'hereby'. For example, "I hereby ask you what time it is" expresses a question and "I hereby confirm my reservation" a confirmation. In natural dialogue, however, explicit performatives are rarely used and recognition of the force may come from other utterance features.³ In Austin (1962) other devices, apart from situational aspects, that may contribute to the recognition of the illocutionary force are also discussed:

Mood: By mood Austin refers to what we will call *sentence type*, e.g., 'declarative', 'interrogative' and 'imperative'. Some examples are:⁴

sentence type	example	illocutionary force
Declarative	John drinks beer	statement
Interrogative	Does John drink beer	question
Imperative	Drink beer John	order or request

Tone of voice, cadence, emphasis: Henceforth, these features will be called *prosodics*. In written language they may be replaced by punctuation, italics, etc. Some examples are:

³ The explicit performative is not even decisive in all cases. For instance, in the appropriate circumstances and with the proper intonation pattern, the utterance "I promise you that I will return" can be meant as a *warning* and not as a sincere act of *promising*.

⁴ See Geukens (1986) for an extensive discussion on the relation between sentence type and illocutionary force.

Prosodics	example	illocutionary force
final fall	There is a dog in the house.	statement
final rise	There is a dog in the house?	question
accentuation	There is a DOG in the house!	warning

Connecting particles: Some particles may replace the use of an explicit performative. For instance, the particle ‘still’ may indicate ‘I hereby insist that’; ‘therefore’ and ‘so’ indicate ‘I hereby conclude that’, etc.

Accompaniments of the utterance: Utterances may be accompanied by non-verbal phenomena, like gestures (winks, pointing, frowning, etc.) or ceremonial non-verbal activities.

Although these devices may give important hints to indicate the function of the utterance, it is not to be expected that in general a one-to-one relation will ever be found between sentence features and the illocutionary force of an utterance (see e.g., Huddleston (1976), Levinson (1983) and Perrault (1990) for extensive discussions); the relation will be hampered in particular by the influence of contextual features. For instance, depending on the circumstances, a declarative can be used as a statement, an acknowledgement, or even a question. We may hope that in spoken dialogues information about the function comes from prosodics. However, this hope is often vain. For instance, in Geluykens (1988) it has been shown that (at least in British English) in many cases intonation is not used to distinguish sincere questions from interrogatives without question status. Even in cases where a declarative sentence type was used, a falling intonation pattern was by far the most frequent pattern (68%). Our findings confirm this for Dutch (Beun, 1989). Hence, any formal framework developed for speech act recognition and communicative effects should have a possibility to include contextual aspects of the utterance in terms of the previous mental states of the dialogue participants (see also Perrault, 1990).

2. A framework for representing communicative acts

2.1. Beliefs

To represent that an agent x has a certain belief or weak belief at a certain time t that p , we will write $B_{x,t}p$ or $WB_{x,t}p$, respectively. Both expressions are of the type *proposition*; the variables x and t are universally quantified. Weak belief is included to express people’s uncertainty about some propositions and is mainly used in relation to verifications (Bunt, 1989; Beun, 1990b). $\bar{B}_{x,t}p$ will be used as a shorthand notation for $B_{x,t}p \vee B_{x,t}\neg p$, and can be read as ‘ x has a belief about p at time t ’.

We will assume that belief possesses the properties of the standard weak S5 axioms (see e.g., Hughes and Cresswell, 1968):

Consistency	$\vdash B_{x,t}p \rightarrow \neg B_{x,t}\neg p$
Closure	$\vdash B_{x,t}p \& B_{x,t}(p \rightarrow q) \rightarrow B_{x,t}q$
Positive Introspection	$\vdash B_{x,t}p \rightarrow B_{x,t}B_{x,t}p$
Negative Introspection	$\vdash \neg B_{x,t}p \rightarrow B_{x,t}\neg B_{x,t}p$

These rules are closed under the principle:

Necessitation If $\vdash p$ then $B_{x,t}p$

where p is an axiom of (standard) propositional logic.

To indicate a common belief of two agents, we will use mutual belief $MB_{x,y,t}p$ (which is equivalent to $B_{x,t}p \& B_{y,t}p \& B_{x,t}B_{y,t}p \& B_{y,t}B_{x,t}p \& \dots$).

The addition of time motivates two new axioms expressing that agents remember their beliefs over time (Memory) and continue to hold them (Persistence) (see Perrault, 1990):

Memory	$\vdash B_{x,t}p \rightarrow B_{x,t'}B_{x,t}p$
Persistence	$\vdash B_{x,t'}B_{x,t}p \rightarrow B_{x,t}p$

where $t < t'$.

Note that the Memory axiom is a time-dependent modification of the S5 axiom Positive Introspection and that the combination of Memory and Persistence has the consequence that an agent never changes his or her old beliefs.⁵

2.2. Intention

The intention operator (I) is introduced, as opposed to wants and desires, to concentrate on the goal-directed behaviour of the participants in an information dialogue. If a speaker intends to do a communicative act, then he or she has decided to do the act, which is clearly not the case with a desire. Bratman (1990) argues that desires can be inconsistent with someone's belief, but intentions are always assumed to be consistent. He distinguishes two types of intention: first to characterize an agent's actions, and second, to characterize an agent's mental state. In our framework, intentions should be considered as the decision of an agent to achieve a certain state of affairs, and can thus be seen as a description of an agent's mental state (namely the intended state).

⁵ Clearly, we are not sketching a framework with full psychological validity, since people change their beliefs over time. Adding this possibility to the framework would make the situation much more complicated. However, we should be aware of these restrictions.

We will assume that a rational agent does not intend to do superfluous acts. In other words, if an agent intends to achieve a situation in which p is true, he believes that p is false (BI1, below). This axiom can be seen as an extreme form of Allwood's principle of adequacy: "Try to act as adequately and efficiently as possible to achieve your intended purpose" (Allwood, 1976: 49). It would be very inadequate of agents if they tried to achieve a certain goal which they believed has already been achieved.⁶

Moreover, intentions are supposed to be consistent with an agent's belief; so, if the agent intends to achieve a situation in which p is true and he believes that from p follows q , he does not intend to achieve a situation in which q is false. This is expressed in axiom BI2. In axiom BI3 it is expressed that if an agent intends to achieve a certain state where p is true and believes that p and q are equal, he or she also intends to achieve a state where q is true. The axioms BI4 and BI5 are added to express the agent's introspective view on his or her intentions.

- BI1 $\vdash I_{x,t}p \rightarrow \neg B_{x,t}p$
 BI2 $\vdash I_{x,t}p \& B_{x,t}(p \rightarrow q) \rightarrow \neg I_{x,t} \neg q$
 BI3 $\vdash I_{x,t}p \& B_{x,t}(p \leftrightarrow q) \rightarrow I_{x,t}q$
 BI4 $\vdash I_{x,t}p \rightarrow B_{x,t}I_{x,t}p$
 BI5 $\vdash \neg I_{x,t}p \rightarrow B_{x,t} \neg I_{x,t}p$

Note that due to axiom BI2, an agent will never intend both p and $\neg p$ at the same time ($I_{x,t}p \& B_{x,t}(p \rightarrow \neg p) \rightarrow \neg I_{x,t} \neg p$). It should be stressed here that the axioms on intention are far from complete and are only mentioned to indicate some of the principal characteristics of intentions. A more sophisticated framework is sketched in Cohen and Levesque (1990b).

2.3 Action

To indicate that an agent x performs a certain action a between time t and t' , we will use the expression $DO_{x,t-t'}a$, which is also of type proposition. a is of type action, and $Obs(DO_{x,t-t'}a)$ is of type action denoting the action of observing the action performed by agent x . The time-points t and t' represent respectively the beginning and end points of the interval where the action takes place. They are taken from $(\mathcal{T}, <)$, i.e. the set $\mathcal{T}$ with a strict total order $<$, where $t < t'$.

By considering communicative acts as special instances of actions, the performance by x of the communicative act CA can be expressed as $DO_{x,t-t'}(CA)$. A communicative act is denoted by an n-tuple called 'action structure'

⁶ Note also the similarity with the second Gricean maxim of quantity (Grice, 1975): "Do not make your contribution more informative than is required".

(*Astruc*), consisting of the class of utterance features ($f1, f2, \dots, fn$) that contributes to the *functional* aspects of the utterance and the semantic content (*semc*) of the sentence. $x1, x2, \dots, xn$ and p represent the concrete values of the features and the semantic content, respectively. To avoid unnecessary complexity, the semantic content will be restricted to propositions only.

(1) CA: *Astruc*($f1 : x1; f2 : x2; \dots; fn : xn; semc : p$)

In the examples below, we will restrict the number of classes of functional utterance features to three, *sentence type*, *particle* and *prosodics*, respectively. We will restrict $x1, x2$ and $x3$ to the following values:

(2) $x1 \in \{\text{declarative, interrogative}\}$
 $x2 \in \{\text{dus, wel, nil}\}$
 $x3 \in \{\text{final}[+], \text{final}[-], \text{nil}\}$

The value ‘nil’ indicates that information about a particular feature is absent. The values ‘final[+]’ and ‘final[-]’ indicate a final rise and fall, respectively, in the intonation pattern of the utterance. If prosodic information is not available, for instance in written discourse, ‘final[+]’ and ‘final[-]’ may indicate punctuation, here ‘question mark’ and ‘full stop’, respectively. It should be mentioned, however, that this is a simplification, since the function of prosodic markers and punctuation in natural discourse often does not agree.

For instance, if speaker S utters the sentence “Dus, Jan is dronken” (“So, John is drunk”) between time t and time t' , this will be represented by the following expression:

(3) $DO_{S,t-t'}(\text{Astruc}(\text{sentt: declarative};$
 $\text{part: dus};$
 $\text{pros: nil};$
 $\text{semc: DRUNK(JOHN)}))$

Note that in this case we do not have any information available about the prosodics of the utterance. Below, a shorthand notation will be used. For instance, (3) will be represented as:

(4) $DO_{S,t-t'}(\text{dec, dus, } p)$

where p is the proposition DRUNK(JOHN). If no information is available about a particular feature (in this case the prosodics), the field will be left out.

2.4. Default rules

The link between the communicative act and the mental state of speaker and hearer will be established by default rules. The application of default logic (Reiter, 1980) to specify action consequences was introduced in Perrault (1990). In default logic consequences from an utterance can be inferred only as long as they do not contradict the context of the utterance. An important advantage of this approach is that consequences can be inferred without having to specify all the possible (counter-) arguments.

A default theory consists of a set of default rules D and a set of assumptions W of well-formed formulas. In line with Perrault, we will use so-called normal defaults only, which are of the form:

$$(5) \frac{p:Mq}{q}$$

where p is the *prerequisite* and q the *consequent* of the rule, Mq expresses that q is possible given a certain set of beliefs. Normal defaults are abbreviated as $p \Rightarrow q$, and intended to mean that if p is believed, q is believed as long as q is consistent with what is believed.

Default rules should be considered as rules of inference, like Modus Ponens, rather than axioms. The closure of a default theory is called an *extension* and contains: (1) the assumptions W , (2) the closure under the logical axioms, and (3) the consequents of the default rules as long as the consequents do not contain the negation of formulas in logical closure and of previously derived default consequents. (Note that the latter restriction makes the derivation dependent of the sequence of application of the default rules.) For more details, see Reiter (1980).

Here, we will introduce two default rules. First, if an agent x has the intention to let the other believe that p is true, x believes that p is true by default (Quality). Note that this rule resembles closely the Gricean maxim of quality (Grice, 1975) and the Searlean sincerity condition on asserting. Second, belief from another agent will be taken over as long as this new belief is consistent with the ones already held (Belief Transfer; Perrault, 1990).

$$\begin{array}{ll} \text{Quality} & I_{x,t}B_{y,t'}p \Rightarrow B_{x,t}p \\ \text{Belief Transfer} & B_{x,t}B_{y,t'}p \Rightarrow B_{x,t}p \end{array}$$

where $t < t'$.

We do not need to restrict the Quality rule to cases where $x \neq y$, since, if $x =$

y , the default $B_{x,t}p$ will be rejected by the closure under the logical axioms.⁷

Default rules are closed under belief by a meta-rule:

if $p \Rightarrow q$ is a default rule, then so is $B_{x,t}p \Rightarrow B_{x,t}q$

Perrault also suggests another version of the quality rule, namely a rule that expresses that the content of a declarative is believed to be true:

Declarative rule $DO_{x,t-t'}(dec,p) \Rightarrow B_{x,t}p$

It should be stressed, however, that we will deviate slightly from this point of view, since we are especially interested in the linguistic features that can be connected to a particular mental state. The rule is added here to explain the mechanism of the framework.⁸

Now, we are able to make predictions for the update of the existing context when the usual felicity conditions of communicative acts do not obtain (e.g. in cases of lies or irony). It is important to note that the context will be updated by inferences based on the utterance and its previous context. For instance, suppose a speaker S utters a declarative with content p , and a hearer H , who observes S , believes that S is lying. In other words, the assumptions W contain the formula $B_{H,t}B_{S,t}\neg p$, which is, according to the belief axioms that were introduced, inconsistent with $B_{H,t}B_{S,t}p$. Therefore, the default inference from the Declarative rule that $B_{S,t}p$ will be blocked and therefore H will not come to believe that p is the case.⁹

The so-called non-monotonic default rules in Perrault's theory seem to correspond to a formalization of standard pragmatic inferences. In non-monotonic reasoning, inferences can be made without complete knowledge of the situation. In a classical monotonic system, we could for instance have the following rule:

(6) $DO_{S,t-t'}(dec,p) \& \neg LIE(S) \rightarrow B_{S,t}p$

(A speaker believes the content of an uttered declarative unless he is lying.) From this rule it can only be inferred that the speaker believes p if it is explicitly known that the speaker is not lying. By contrast, in non-monotonic reasoning the consequent can be derived unless it can be proved that the

⁷ The default will be rejected if we can prove the logical axioms that $\neg B_{x,t}p$. This proof goes roughly along the following lines. Suppose that $I_{x,t}B_{x,t}p$. With B11 we get $\neg B_{x,t}B_{x,t}p$, from which we can easily derive by Memory, Persistence, Closure and Necessitation that $\neg B_{x,t}p$.

⁸ The main differences between Perrault's framework and ours will be worked out in the discussion.

⁹ In the proof the belief closure for default rules should be applied.

hearer is lying; therefore, the consequent can be derived in the absence of any belief about the speaker's lying.

2.4.1. Hierarchical default rules

In deriving the mental state from the speaker's utterance, a crucial role is played by the *priorities* of default rules. We will say that:

Default rule $\phi : \phi_1 \Rightarrow \phi_2$ has priority over rule $\psi : \psi_1 \Rightarrow \psi_2$ iff $\phi_2 \rightarrow \neg\psi_1$ and $\neg(\psi_2 \rightarrow \neg\phi_1)$ are logically true.

Hence, priority of default rule ϕ over rule ψ implies that the consequent of ψ can be inferred only in the event that the consequent of ϕ is logically false. The second conjunct ($\neg(\psi_2 \rightarrow \neg\phi_1)$) prevents that rule ψ has priority over rule ϕ .

Let us take an example. Suppose we have a default theory that contains the following defaults only:

(7) a: $p \Rightarrow q$, b: $p \& \neg q \Rightarrow r$, s: $\neg q \& \neg r \Rightarrow m$

It can easily be verified that rule (a) has priority over rule (b) and that both (a) and (b) have priority over (c). Note that r can only be derived if it has explicitly been proved that the consequent of (a) is false, i.e. q is false. Now, if we substitute, for instance, p by the expression 'S' utterance is a declarative', q by 'S' utterance is a statement', and r by 'S' utterance is a verification', we are able to express that a declarative is usually meant as a statement and only in those cases where it can explicitly be proved by the closure of the assumptions that the utterance is not a statement is it meant as a verification. Proof to the contrary may come, for instance, from previous utterances in the conversation. Below, the example will be worked out in detail.

3. Mental state and utterance features

We will follow Bunt's (Bunt, 1989) idea that the utterance communicates its felicity conditions (FCs). But, since identical utterance features can be linked to different packages of FCs and, depending on the context, packages may have different priorities, we will express that a particular interpretation is preferred in a certain situation. Here, default rules will play an important role because these rules enable to express that, in uttering a declarative, a speaker *usually* intends the hearer to believe the content of the declarative. Only where it can explicitly be proved that this is not the case will this interpretation be rejected. Therefore, we will speak of a *preferred set* of felicity conditions as a mental state description rather than as a direct or indirect interpretation

of a communicative act. Different FCs will be hierarchically linked to the linguistic features of the utterance. Although the preferred set FCs of a simple declarative (i.e., of $DO_{S,t-t'}(dec,p)$) is closely related to its usual direct interpretation, it is important that we do not take the view that less preferred sets have to be considered as indirect (Searle, 1975). Searle calculates the indirect act from the direct one; here, we will see that if a preferred set is inconsistent with, for instance, prior knowledge, the set is rejected by means of the application of default rules in a certain order before it is even calculated.

3.1. Sentence type and felicity conditions

Before we try to answer how the FCs can be linked to particular utterance features, let us make some assumptions. First, we will assume that the preferred interpretation of a simple declarative agrees with a statement interpretation and that the preferred interpretation of a simple interrogative (i.e., $DO_{S,t-t'}(int,p)$) agrees with a question interpretation. Second, we will assume that, in all cases, the speaker has the intention that the hearer should believe something. If the utterance is declarative, the speaker intends the hearer to believe the content of the utterance; if interrogative, the speaker intends the hearer to believe that the speaker wants to know the content of the question.

It is important to note that different priorities may be applied in different contextual settings. Our choice is based on results from recorded dialogues where information was exchanged about arrival and departure times of aircraft and trains, so-called information dialogues (see e.g., Bunt, 1989). In a classroom situation, for instance, it may be preferred to give priority to the rule that says that, if the student utters a declarative sentence in answer to the teacher's question, it should be interpreted as 'the student intends the teacher to believe that the student believes p '. The interpretation 'the student intends the teacher to believe p ' would be in conflict with the Gricean quantity principle and our rule BI1, since the teacher already knows the answer.

The use of time-dependent states commits us to formal adjustments of the FCs, since, if they behave rationally, agents will not intend to achieve states which they believe are impossible to achieve. Hence, agents do not believe that the effects of their acts will appear before they have been performed. In the case of a declarative with content p , the speaker does not intend that the hearer believes p before the act is accomplished, that is before time t' . Also, in the event of an interrogative, it can never be the intention of the speaker to have a belief about p before t'' , since the hearer can only give the answer after time t' .

The interrogative case partly agrees with Searle's (1969) FCs on questioning. In this paper, the 'preparatory' condition on questioning, viz. that the

speaker does not know the answer, follows from the axiom BI1. If x has the intention to make p true, x does not believe that p is true at that moment:

$$\text{BI1 } I_{x,t}p \rightarrow \neg B_{x,t}p$$

If x is replaced by the speaker S and p by $\bar{B}_{S,t'}p$, that is, the speaker has the intention to know the value of p at time t' ($I_{S,t'}\bar{B}_{S,t'}p$), it follows that S does not believe that S believes whether p at time t'' :

$$(8) I_{S,t}\bar{B}_{S,t'}p \rightarrow \neg B_{S,t}\bar{B}_{S,t'}p$$

From (8) it can easily be proved, by means of the belief axioms, that the speaker has no belief about p at time t ($\neg \bar{B}_{S,t}p$).¹⁰ This implies that Searle's preparatory condition need not be included explicitly in the FCs and that the condition follows from general axioms on the rational behaviour of the speaker.

This results in the following preferred package of felicity conditions of the simple declarative and the simple interrogative:

$$(9) \text{ declarative: } FC_{S,H,d,t}(p) = I_{S,t}B_{H,t}p$$

$$(10) \text{ interrogative: } FC_{S,H,i,t}(p) = I_{S,t}B_{H,t}I_{S,t}\bar{B}_{S,t'}p$$

where $t < t' < t''$.

3.2. The application of the default rules

We now formulate default rules where the communicative act is represented in the prerequisite of the rule and the preferred package of felicity conditions in the consequent. In other words, the general case of the preferred interpretation always has the form:

$$(11) DO_{x,t-t'}(CA) \Rightarrow FC_{x,y,CA,t}(p)$$

¹⁰ From $\neg B_{S,t}\bar{B}_{S,t'}p$ we have to prove that $\neg \bar{B}_{S,t}p$. This proof roughly goes along the following lines.

$\vdash B_{S,t}p \rightarrow B_{S,t}B_{S,t}p$	Positive Introspection
$\vdash B_{S,t}B_{S,t}p \rightarrow B_{S,t}B_{S,t'}p$	Memory, Persistence, Closure
$\vdash B_{S,t}B_{S,t'}p \rightarrow B_{S,t}(B_{S,t'}p \vee B_{S,t''}\neg p)$	pL, Closure
$\vdash B_{S,t}(B_{S,t'}p \vee B_{S,t''}\neg p) \rightarrow B_{S,t}\bar{B}_{S,t}p$	$\equiv$, Closure

The same result can be found with $\neg p$ instead of p . So, we may conclude that $(B_{S,t}p \vee B_{S,t}\neg p) \rightarrow B_{S,t}\bar{B}_{S,t}p$ or, since $\bar{B}_{S,t}p \equiv (B_{S,t}p \vee B_{S,t}\neg p)$, we also have $\bar{B}_{S,t}p \rightarrow B_{S,t}\bar{B}_{S,t}p$. In words, if an agent believes certain information, the agent believes that he will continue believing the information. Now, with contraposition we get the result $\neg B_{S,t}\bar{B}_{S,t}p \rightarrow \neg \bar{B}_{S,t}p$. $\square$

where x performs the communicative act CA with content p at time t towards y . Thus, if a speaker utters a simple declarative or interrogative, respectively, it can be inferred by default that the felicity conditions $FC_{S,H,d,t}(p)$ or $FC_{S,H,i,t}(p)$ hold.

$$(12) DO_{S,t-t'}(dec,p) \Rightarrow I_{S,t}B_{H,t'}p$$

$$(13) DO_{S,t-t'}(int,p) \Rightarrow I_{S,t}B_{H,t'}I_{S,t}\bar{B}_{S,t'}p$$

In the expressions below the following abbreviations will be used:

$$STATE(p) \equiv I_{S,t}B_{H,t'}p$$

$$QUE(p) \equiv I_{S,t}B_{H,t'}I_{S,t}\bar{B}_{S,t'}p$$

Empirically, a 'statement' interpretation of declaratives is preferred; however, a declarative can be used for questioning even without any overt question indicators. In Beun (1989) it was shown that an important number of questions in Dutch spoken dialogues possess a declarative sentence type and that no more than 50% of these question possess an overt question indicator, such as a rising intonation. Therefore it is desirable to be able to infer both interpretations, with a preference for the statement as long as no evidence exists to the contrary. Only if it can be proved that $\neg I_{S,t}B_{H,t'}p$, can the 'question' function be chosen and only then should the 'statement' interpretation be rejected.

The priority of default rules now comes into play. Simply adding the negation of the consequent of (12) to the prerequisite of the question interpretation of the declarative results in the priority of the statement interpretation.

Moreover, in Beun (1990a), it was experimentally shown that questions in Dutch with a declarative sentence type usually have a verificative function, i.e., apart from the usual felicity conditions of the interrogative, the speaker intentionally communicates that he or she suspects that p . So, the second interpretation of the declarative can be written as:

$$(12a) DO_{S,t-t'}(dec,p) \& \neg STATE(p) \Rightarrow QUE(p) \& I_{S,t}B_{H,t'}WB_{S,t}p$$

To infer the consequent of (12a) it should explicitly be proved that the speaker has no intention to let the hearer believe that p is true, which is always true if the consequent of (12) is rejected. This implies that (12) has priority over (12a).

Depending on the discourse situation other functions may be found as well, although the verificative function is preferred in the spoken information dialogues that we have analysed (Beun, 1990a). If the speaker has no suspicion about the content of the declarative question, a third default rule could be applied, viz.

$$(12b) DO_{S,t-t'}(dec,p) \& \neg STATE(p) \& \neg I_{S,t} B_{H,t'} WB_{S,t} p \Rightarrow QUE(p)$$

Again, the consequent of (12b) can be inferred only if the consequents of (12) and (12a) cannot be inferred and therefore the last-named have priority.

Note that the inference in (12) cannot be made by ordinary implication. (14) as a replacement is problematic because $\neg QUE(p)$ must explicitly be proved to infer the consequence, which is impossible in most realistic cases.

$$(14) DO_{S,t-t'}(dec,p) \& \neg QUE(p) \rightarrow STATE(p)$$

Also (15) is unacceptable, because in all cases $STATE(p)$ would be inferred if the speaker utters a declarative, even if it is already known by the hearer that $\neg STATE(p)$.

$$(15) DO_{S,t-t'}(dec,p) \rightarrow STATE(p)$$

3.3. Other linguistic features

3.3.1. Final rise

An important feature revealing the question function of a declarative is a final rise in intonation, although not all declaratives with a final rise are meant as questions (Geluykens, 1987). Most declaratives with a final rise can be given a question interpretation; only where it can be proved that the utterance is not a question, will a statement interpretation be selected. This can be expressed by the following default rules:

$$(16a) DO_{S,t-t'}(dec,final[+],p) \Rightarrow QUE(p) \& I_{S,t} B_{H,t'} WB_{S,t} p$$

$$(16b) DO_{S,t-t'}(dec,final[+],p) \Rightarrow \& \neg QUE(p) \Rightarrow STATE(p)$$

In this case the meaning of the final rise is expressed in the change of priority of the default rules from statement to question interpretation, which is expressed in a change of the preferred set of felicity conditions.

3.3.2. The particle 'dus' ('so')

In Beun (1990b) it was demonstrated that if the Dutch particle *dus* (*so*) is added to an utterance which was interpreted as a statement in the absence of the particle (no punctuation or prosodic information being available), the addition of the particle turns the utterance interpretation into a question. The presence of the particle therefore turns the priority from statement to question interpretation.

$$(17a) DO_{S,t-t'}(dec,dus,p) \Rightarrow QUE(p) \& I_{S,t} B_{H,t'} WB_{S,t} p$$

$$(17b) DO_{S,t-t'}(dec,dus,p) \& \neg QUE(p) \Rightarrow STATE(p)$$

Again, the meaning of the particle is hidden in the application of the default rules and the preferred set of felicity conditions. A further analysis of *dus* will not be pursued, since our framework is far from sufficient to account properly for the information that can be expressed by the particle.

4. Communicative effects and the influence of context

4.1. Mutual belief as a communicative effect

The notion of communication can explicitly be built into the Observability axiom (Perrault, 1990) expressing that if agent x performed the action a and agent y was observing x doing the action, then y believes afterwards that x was performing the act.¹¹

$$\text{Observability} \vdash DO_{x,t-t'}a \& DO_{y,t-t'}Obs(DO_{x,t-t'}a) \rightarrow B_{y,t'}(DO_{x,t-t'}a)$$

Formally, x and y need not be different; communication is only established when x and y differ. Now, suppose that x is performing the communicative act CA and x and y mutually observe each other. This implies that y observes x 's act, x observes his or her own act, y observes x 's observation, x observes y 's observation, ad infinitum. These mutual observations can be defined recursively in the following way (below x' and y' are shorthand notations for $x, t-t'$ and $y, t-t'$, respectively):

$$(18) \alpha_{x'} \stackrel{\text{def}}{=} DO_{x'}Obs(DO_{x'}(CA) \& \alpha_{x'} \& \beta_{y'})$$

$$(19) \beta_{y'} \stackrel{\text{def}}{=} DO_{y'}Obs(DO_{x'}(CA) \& \alpha_{x'} \& \beta_{y'})$$

where $\alpha_{x'}$ and $\beta_{y'}$ represent x and y 's observations, respectively.

Now, assume the following axiom:

$$(20) \vdash DO_{x'}Obs(\gamma_{t-t'}) \& DO_{x'}Obs(\delta_{t-t'}) \leftrightarrow DO_{x'}Obs(\gamma_{t-t'} \& \delta_{t-t'})$$

(20) expresses that if x observes action γ and x observes action δ , and both γ and δ take place at the same interval $t-t'$, then x observes both γ and δ and vice versa. Axiom (20) enables us to split up the agents' observations in logical conjunction consisting of x 's communicative act, x 's observations and y 's observations in the following way:

$$(21) \alpha_{x'} = DO_{x'}Obs(DO_{x'}(CA)) \& DO_{x'}Obs(\alpha_{x'}) \& DO_{x'}Obs(\beta_{y'})$$

¹¹ In Perrault (1990) the axiom is slightly oversimplified, since agents rather than actions are observed.

$$(22) \beta_{y'} = DO_{y'} \cdot Obs(DO_{x'}(CA)) \& DO_{y'} \cdot Obs(a_{x'}) \& DO_{y'} \cdot Obs(\beta_{y'})$$

In describing the communicative effects we will use the Observability axiom, so that communication is explicitly built into the axioms. We will consider the initial state W , where speaker S and hearer H mutually observe their actions, and where the speaker performs the act CA : $\{DO_{S,t-t'}(CA), a_{S,H,t-t'}, \beta_{S,H,t-t'}\}$. By means of the Observability axiom, it can be inferred that, at time t' , both S and H come to believe that S performed the act and that S and H mutually observe each other:

$$(23) B_{S,t'}(DO_{S,t-t'}(CA) \& a_{S,t-t'} \& \beta_{H,t-t'}) \& B_{H,t'}(DO_{S,t-t'}(CA) \& a_{S,t-t'} \& \beta_{H,t-t'})$$

The inference can be applied ad infinitum, so that in the closure set of the axioms and the initial situation we can derive that the initial situation is mutually believed at time t' :

$$(24) MB_{S,H,t'}(DO_{S,t-t'}(CA) \& a_{S,t-t'} \& \beta_{H,t-t'})$$

By means of the weak S5 axioms, (11), the Declarative rule and the closure rule for defaults, it can be inferred from (24) that, *by default*, it is mutually believed that the felicity conditions hold:

$$(25) MB_{S,H,t'} FC_{S,H,CA,t}(p)$$

The inference from (25) that the hearer comes to believe the content of a declarative by default is only a small step. Since mutual belief that p implies belief that p by both agents (see section 2.1), we may infer from (25) that the hearer believes that the felicity conditions hold:

$$(26) B_{H,t'} FC_{S,H,CA,t}(p)$$

Since $FC_{S,H,d,t}(p) = I_{S,t} B_{H,t} p$, we would get the following result in the special case of a simple declarative:

$$(27) B_{H,t'} I_{S,t} B_{H,t} p$$

That is, the hearer believes that the speaker intends the hearer to believe p . By means of the Quality rule, it can be inferred that the hearer believes at time t' that the speaker believes p at time t by default:

$$(28) B_{H,t'} B_{S,t} p$$

From this, the hearer may conclude by Memory and Persistence that the

speaker believes p at time t' ($B_{H,t'}B_{S,t'}p$). Next, Belief Transfer leads to the default inference that the hearer believes the declarative at time t' :

$$(29) B_{H,t'}p$$

In conclusion, we may say that, if a speaker S performs a communicative act and the act is observed by S and the hearer H , and S and H observe each other's acts (both communicative and non-communicative), then we may infer that, after the performance of the act, S and H mutually believe by default that the felicity conditions of the communicative act hold. In the special case of a simple declarative, a hearer may come to believe the content of the declarative if he or she assumes that the speaker behaves cooperatively (or sincerely) and if he or she has no proof to the contrary.

4.2. Contextual dependency

Now suppose that, for whatever reason, the speaker and hearer mutually believe that the preferred FCs do not hold at time t . Then the default inference (25) will be blocked and both participants will believe that a less preferred package of FCs holds (as long as the interpretation is consistent with the previous beliefs). Finally, let us demonstrate this by an example where a simple declarative is used as a question.

In Beun (1990b) it was pointed out that (30) is an important consideration in determining whether a declarative utterance U was used as a question.

$$(30) MB_{S,H,t}Expert_H(topic(U))$$

That is, it is mutually believed by speaker S and hearer H that H is the expert on the topic of the utterance. It was experimentally verified that utterances which fulfil these conditions (like "You want to go Amsterdam" or "You know what time it is") are usually interpreted as questions. A precise definition of the notions 'expert' and 'topic' was omitted in Beun (1990b) and will also be left out in this paper.

The following axiom expresses that if a speaker performs a simple declarative and it is mutually believed that the hearer is the expert on the propositional content p of the declarative,¹² then it is not the intention of the speaker that the hearer believes that p is true.

$$(31) \vdash MB_{S,H,t}Expert_H(topic(p)) \& DO_{S,t-t'}(dec,p) \rightarrow \neg I_{S,t}B_{H,t'}p$$

¹² For reasons of simplicity, we will assume that the hearer is the expert on the content p of the utterance U , and not, as indicated in (30), the expert on the topic of U .

Now, suppose that it is initially believed that S and H mutually observe each other and that it is mutually believed that the hearer is the expert on the proposition p (the first conjunct of (31)). If a speaker utters a simple declarative with content p (the second conjunct of (31)), it can be inferred that the speaker does not intend the hearer to believe that p is true (the consequence of (31)). Since the default consequent of (32) will be rejected, a less preferred interpretation will be chosen, namely the verification interpretation in (33):

$$(32) DO_{S,t-t'}(dec,p) \Rightarrow I_{S,t}B_{H,t'}p$$

$$(33) DO_{S,t-t'}(dec,p) \& \neg I_{S,t}B_{H,t'}p \Rightarrow I_{S,t}B_{H,t'}(I_{S,t}B_{S,t''}p \& WB_{S,t}p)$$

So, after closing the default rules and the axioms, speaker and hearer mutually believe that the declarative was meant as a verification:

$$(34) MB_{S,H,t}I_{S,t}B_{H,t'}(I_{S,t}\bar{B}_{S,t''}p \& WB_{S,t}p).$$

5. Discussion

5.1. A comparison with other theories

The main problem to be solved in this paper was to find a formalism for describing how linguistic features of utterances could transfer information about a speaker's mental state to a recipient. Therefore an utterance was taken as a communicative act which figures in a framework of default rules. In line with Bunt (1989), the communicative act was defined as the application of a communicative function to a propositional content. The communicative function consisted of those features that contributed to revealing a speaker's attitude towards the content of the utterance. However, Bunt's theory and the one presented in this paper are aimed at different problems.

Our view concerns an identification problem; Bunt attempts to define communicative acts as changes in the mental state of both speaker and hearer and formalizes the acts as a function from context to context, in terms of the felicity conditions of the act and the update function. In this paper, the communicative act is denoted by an utterance with certain features (and propositional content). The felicity conditions follow by default from the utterance and, from this, a hearer can infer the attitudes which are responsible for the performance of the communicative act. Bunt's update function would follow from the closure of the axioms and default rules. Note that both views can lead to the same inferences, since in both cases it was derived that the agents mutually believe that the felicity conditions hold. In our case this is explicitly achieved by means of the observability axiom.

The framework presented here differs in a few important ways from that of Perrault (1990) as well. We have already mentioned the inclusion of relevant pragmatic properties in the sentence, the priority of the default mechanism and the explicit representation of the felicity conditions in the consequences of the default rules. Moreover, Perrault seems to have a different view on the meaning of the intention operator, which is reflected in some of his intention axioms. For instance, in our paper we left out Perrault's closure rule for intention, i.e:

$$(35) I_{x,t}p \& B_{x,t}(p \rightarrow q) \rightarrow I_{x,t}q$$

The reason for this is given in Cohen and Levesque (1990b): an agent who decides to get his or her tooth filled and believes that the dentist's action will cause pain, may surely deny that he *intends* to be in a state of having pain. In other words, the agent need not intend all the expected side-effects of his or her intentions. In our proposal, we have opted for a weaker form of the consequence, i.e., $\neg I_{x,t}\neg q$. From this it follows that intentions are always consistent (see section 2.2) and therefore, we do not have to include Perrault's extra axiom on the consistency of intentions.

We take the view that the intentional attitude of the agent is *the state to be achieved*, more specifically a certain belief state, not the action to be performed. Although an action in its propositional form may be used as an object of the intention operator ($DO_{x,t}\neg a$ is of type proposition), this is not what we mean here. In our paper, the actions that follow from the actor's intention are *implicitly* considered as intentional. For instance, if the speaker intends the hearer to believe that p is true, the speaker may decide to perform intentionally a declarative with content p . This commits the speaker to formulate a certain sentence and do so, a speaker should pick up a pen or open his mouth, etc. In other words, a great deal of intended, parallel and sequential actions are involved to achieve the primary intention of making the other believe that p . An explicit distinction between the two types of intention (directed towards state or towards action) goes beyond the scope of this paper and should be worked out in the future.

The advantage of using a non-monotonic system is that inferences can be drawn without complete knowledge of the actual state of affairs. It is our impression that the particular choice of the non-monotonic system (Reiter's (1980) default logic) is rather arbitrary; one might as well choose other systems like Moore's (1985) autoepistemic logic or Appelt and Konolige's (1988) (A&K) extended version of Moore's logic. In A&K's proposal alternatives are worked out to solve some problems of Perrault's theory. In the proposal, *hierarchical sets* of extensions are generated to incorporate preferences among defaults. Our notion of priority of defaults differs from A&K's proposal in

that priority is built into the default rules themselves, whereas A&K build priority into a hierarchical structure of subtheories.¹³

5.2. *Illocutionary categorization*

An important result to be mentioned is that illocutionary categorization of utterances can be omitted in language understanding. What is important, is that the hearer is able to infer the attitude(s) communicated by the speaker. In this respect, illocutionary acts can be considered as abbreviations for sets of felicity conditions, in this paper expressed in terms of belief and intention.

In other words, the calculation of the illocutionary act seems to be redundant for the determination of the functionality of the utterance. It may even be argued that the calculation of the act should be avoided, simply because the language does not provide enough performative verbs to express the subtle differences between different sets of felicity conditions. It is precisely for this reason that Bunt has to introduce artificial performative verbs such as POSI-CHECK and NEGA-CHECK to indicate the subtle differences between two sets of conditions (Bunt, 1989). A POSI-CHECK(*p*) indicates the set that contains the felicity conditions: (1) *S* wants to know whether *p*, (2) *S* suspects that *H* knows whether *p*, (3) *S* suspects that *p*, and (4) *S* suspects that *H* knows that *p*. A NEGA-CHECK only differs from a POSI-CHECK in that (4) has been replaced by (4') *S* suspects that *H* knows that not *p*. Clearly, an extension along different dimensions, such as time (e.g., *S* suspects that *H* knew that ...) and *degrees* of belief or intention, would complicate the matter dramatically and would probably lead to an infinite number of (artificial) performative verbs.

5.3. *The literal force hypothesis and utterance features*

In some respect, our theory can be considered as an extended version of the literal force hypothesis (LFH). The LFH (see Gazdar, 1981) is fully based on the use of explicit performatives or the utterance sentence type, as if no other utterance features, such as particles and intonation, would influence the determination of a speech act type. In our theory, the linguistic features that indicate information on a functional level were filtered from the lexical items that indicate information on the content level. We have investigated only a small number of possible functional features of the utterance. A more sophisticated treatment can be expected if more features are considered. For instance, we may take into account different intonation patterns, or combinations of

¹³ A&K's system is more complex and probably too powerful for our case, since rules like $P(a) \Rightarrow \neg F(a)$ and $B(a) \Rightarrow F(a)$ can be given different priorities, which is impossible in our framework and is unnecessary to formulate what we want to express.

prosodic characteristics such as declination and accentuation. Another point of investigation might be the slope of the final rise in declarative questions, which is probably different from that in other utterances.

Also, the use of particles may give important insight in the intended information transfer. It should be noted, though, that many particles in Dutch (and probably also in English) express mental state aspects that go far beyond the framework presented in this paper. For instance, particles may express surprise ('oh') or a change in belief of the speaker (Dutch: 'wel'). A formalization of surprise should include the concept of expectations and a formalization of belief change should include a mechanism for updating; both aspects were excluded from the limited framework that was presented in this paper.

In this connection a note should be made on the representation of particles in the communicative function. In some cases, a particle indicates how the proposition should be interpreted in a certain universe of discourse (so called *sentence* particles; see van der Auwera and Vandeweghe, 1984); in other cases a particle focuses on certain aspects of the proposition (*focus* particles). Here we have concentrated on the first, i.e. on particles that concern the whole proposition. Focus particles change the proposition and one has to take logical form into account to obtain the meaning of the added particle. For instance, 'too' in "John is drunk too" may indicate that besides John, there is someone else who drunk. In this case, the particle does not influence the attitude towards the proposition, but the proposition itself, and it would therefore be incorrect to place it in the communicative function.

5.4. *The indirect speech act*

An essential difference with traditional inferential theories of indirect speech acts (Levinson, 1983) is that, apart from disregarding illocutionary labelling, the literal force is not computed at all. In our theory, the direct interpretation is rejected as soon as inconsistencies occur in the context. We would even run into contradictory results if a statement as a direct interpretation and a question as an indirect interpretation were treated 'on the same level'. For instance, on the basis of $I_{S,t}B_{H,t}p$ we may infer that the speaker believes that p ; on the basis of $I_{S,t}B_{H,t}I_{S,t}\bar{B}_{S,t}p$, however, we may infer that the speaker does not believe that p . In this paper, this problem was solved by the introduction of hierarchical default rules.

In some cases, building in rules of priority can be problematic. Here, we have decided to give priority to the direct use of declaratives and interrogatives as statements and questions, respectively, but one should be aware that in different situations different priorities could be in force. Ambiguities, on the other hand, can simply be incorporated as disjunctions into the consequents of the default rules. Later on, one might hope, the disjuncts can be disambiguated if more knowledge becomes available in the course of the dialogue.

5.5. *Illocutionary vs. perlocutionary effects*

Another result to be mentioned is that the difference between illocutionary and perlocutionary effects becomes indistinct. Levinson describes illocutionary acts as “what is directly achieved by the conventional force associated with the issuance of a certain kind of utterance in accord with a conventional procedure. In contrast, a perlocutionary act is specific to the circumstances of issuance ... and includes all those effects that some particular utterance in some particular situation may cause” (1983: 237). Here the illocutionary act is replaced by uttering a sentence with particular surface characteristics, and disconnected from the performative verbs. Both the illocutionary act and the utterance of a sentence with particular characteristics can only be performed if a speaker fulfils certain conditions. Hence, the performance of an illocutionary act is also specific to the circumstances of the utterance, just as perlocutionary acts are.

Clearly, an illocutionary act should be described from a speaker’s point of view. As previously discussed, recognition of the act by the recipient in terms of performative verbs is unnecessary for determining the relevant aspects of the speaker’s mental state. A recipient has to know how the utterance features can be related to a package of felicity conditions. Since all effects are contextually dependent on what the hearer thinks about the world, about the speaker, and so on, it can be argued that all effects are perlocutionary.

6. Conclusion

In this paper, the performance of an utterance is taken as a communicative act to influence certain aspects of the mental state of a hearer. To describe the communicative effects that result from the act, communicative acts were expressed in terms of the linguistic features of the utterance and, by means of default rules, connected to the felicity conditions of the act. The felicity conditions were expressed in terms of the speaker’s intentions and beliefs that must be present before the act can be performed. Successful communication is accomplished if a hearer recognizes the felicity conditions from the speaker’s act, which happens when the hearer observes the speaker and knows the conventional relation between the utterance features and its felicity conditions. Felicity conditions could be simplified because aspects of rationality and cooperativity were axiomatized in terms of beliefs and intentions of an agent.

Default rules were used to build in contextual dependency of the interpretation of the act and to enable the agent to draw inferences without complete knowledge of the situation. To indicate that a particular interpretation of a communicative act is preferred in most situations, default rules were hierarchically ordered.

An advantage of our approach is that communicative acts can be viewed as actions in general, intentionally performed with the aim of changing a certain state (here, the mental states of the dialogue participants). In this respect, the agent's intentions may be viewed as his or her commitment to achieve another state by performing a particular action.

Clearly, a lot remains to be done. In the theoretical framework, the conception of time as subsequent states precludes the representation of continuous and parallel events. Also, the framework does not explain *why* people are committed to achieve a certain state, and we are unable to express the strength of the agent's commitment and belief.¹⁴

Moreover, some of the axioms are oversimplified and in most cases particles and intonation can hardly be interpreted in matters as belief and intention only. Also, in cooperative situations, where dialogue participants try to act helpfully, the hearer often goes beyond the intention expressed literally by the felicity conditions of the communicative act. To infer these extrinsic intentions, the introduction of a plan-based analysis cannot be avoided. It is readily agreed that such aspects should be included in a model of natural language understanding, but this would have far-reaching consequences from a formal and a computational point of view.

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¹⁴ We have included, however, a 'weak belief' operator to account for at least two different strengths of belief.

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