The semantics of feedback

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Abstract

This paper proposes a formal semantics for feedback acts in terms of updates of the information states of dialogue participants. A wide range of forms and functions of feedback is considered, including feedback about one's own processing of previous dialogue contributions ('auto-feedback') and feedback about someone else's processing ('allo-feedback'); positive and negative feedback; articulate and inarticulate feedback (having or not having a specified semantic content); feedback which is specific for a certain level of processing and feedback which is level-unspecific, and explicit feedback versus feedback that is entailed or implicated.

1 Forms and functions of feedback

Feedback is the mortar of conversation. Throughout a dialogue, the participants continuously give and elicit information about their attention, perception, understanding, and reactions to what is said by others (Allwood et al., 1993; Clark & Krych, 2004). Feedback is not always expressed explicitly through words or gestures, but may also be implicit, as in the following dialogue fragment:

(1)
1. C: Can you tell me from which platform the train to Utrecht leaves?
2. S: That's platform 5.
3. C: Thank you.

The utterance *"Thank you"* will in this situation be interpreted as implying that participant C understood S's answer, and thus as providing positive feedback by implication.

In general, the receiver of feedback obtains information about the success of his actions. In a dialogue, the receiver of a feedback message obtains information about the sender's success in processing previous contributions to the dialogue. This may tell the receiver for example that he has been understood correctly, or that the speaker is uncertain about what was meant, or has difficulty to believe something that was said. Feedback can thus relate to various levels of processing, such as hearing, understanding, and accepting something. Sometimes, a feedback message is not specific about a particular aspect of processing; for example, common forms of positive feedback such as nodding or saying *"okay"* are often ambiguous in this respect.

1.1 Auto- and allo-feedbeck

Feedback utterances most often provide information about the *speaker's* success in processing previous utterances, but they may also provide information about the speaker's beliefs about *the addressee's success* in processing. Examples are:

(2) a. A: I don't have a good connection on Thursday.
B: I said Tuesday.
b. A: Could you enhance the contrast please?
B: Is this okay?
c. A: Friday 13?
B: That's what I meant.

This kind of feedback was first distinguished by Bunt (1999) and called *'allo-feedback'*, introducing for contrast the term 'auto-feedback' to refer to feedback about the speaker's own processing. Both auto- and allo- feedback can be positive, reporting suc-

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cessful processing, and negative, reporting on processing that is not entirely successful.

Allo-feedback also includes *feedback elicitation*, where the speaker wants to know whether the addressee successfully processed a previous utterance. Like reportative feedback, feedback elicitation may indicate a specific level of processing, like (3c) and (3d) or may be level-unspecific. like (3a) and (3b).

(3) a. Okay?
b. Right?
c. Did you hear me?
d. See what I mean?

1.2 Articulate and inarticulate feedback

A distinction among different forms of feedback concerns the specificity of the feedback. We call feedback *inarticulate* if it reports positively or negatively about the processing of (parts of) one or more previous utterances without specifying which stretch of dialogue the feedback is about (the *scope*) of the feedback), or what the result of the processing or the processing problem was. More precisely, inarticulate positive feedback reports that the processing of (parts of) one or more previous utterances was successful without specifying the scope of the feedback, or what was the result of the processing; negative inarticulate feedback reports that the processing of the utterance parts in its scope was not entirely successful, without specifying the scope or the processing problem. The examples in (4) illustrate this form of feedback.

(4) a. OK. Yes. M-hm. Aha. *(verbally expressed positive auto-feedback)*
Nodding; smiling *(nonverbally expressed positive auto-feedback)*
In combination: *multimodal positive auto-feedback*

b. Excuse me? Huh? What? *(verbal negative auto-feedback)*
Frowning; raising eye brows; head shake *(nonverbal negative auto-feedback)*
In combination: *multimodal negative auto-feedback*

c. Quite. Yes. (positive allo-feedback)
Nodding *(nonverbal positive allo-feedback)*
In combination:*multimodal positive allo-feedback*

d. OK? All right? *(verbal negative allo-feedback)*
Raising eye brows, looking at addressee *(nonverbal negative allo-feedback)*
In combination: *multimodal negative allo-feedback*

Petukhova (2011) found that in the AMI corpus of multiparty dialogues, inarticulate auto-feedback is expressed only verbally in 24.2% of the cases; only nonverbally in 29.6%; and in multimodal form in 46.2%.

In contrast with inarticulate feedback, *articulate feedback* indicates the stretch of dialogue that the feedback is about, typically by repeating or paraphrasing it, and thereby also specifying a processing result. The examples in (5) illustrate this form of feedback.

(5) a. C: Which flights do you have on Friday, in the morning?
S: To Munich, Friday the 23rd, the first flight is at 7.45. (*articulate positive auto-feedback*)

b. Did you say Tuesday or Thursday? *(articulate negative auto-feedback)*

c. Thursday, yes. *(articulate positive allo-feedback)*

d. No, Tuesday. *(articulate negative allo-feedback)*

While inarticulate positive feedback is often expressed nonverbally, articulate feedback is typically expressed verbally or in multimodal form with a verbal component, since the specification of a (part of a) previous utterance and of a processing result is difficult to realize nonverbally (though an iconic or a pointing gesture can sometimes be used for that purpose).

Note that positive articulate feedback need to articulate its scope by repeating or paraphrasing the entire utterance(s) that it contains; often, only a part is repeated or paraphrased, as the examples in (6) illustrate. The paraphrase in (6a) of *"next Friday"* as *"Friday the 13th"* should be understood as positive feedback about the entire previous utterance at the level of understanding.

(6) a. B: We meet again next Friday?
A: Friday the 13th at one-thirty.

b. C: Can you tell me what time is the first train to the airport on Sunday?
S: The first train on Sunday,... let me see..., the first train is at five fifty-four.

By contrast, negative feedback about part of an utterance should not be understood as negative feed-

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back about the entire utterance, but rather as implicating positive feedback about the rest of the utterance, as the examples in (7) illustrate:

(7) a. A: Avon to Bath is four hours.
B: Four?

b. A: then go past the mill, going north,...
B: slightly northeast?

Note that the articulate/inarticulate distinction is one of (linguistic) *form*. A feedback act which is expressed in an inarticulate form does have a semantic content; the difference is that this content is provided by the utterance that the feedback is about, rather than by the feedback utterance itself.

1.3 Feedback scope

For the interpretation of feedback it is essential to know its scope. While articulate feedback explicitly indicates its scope, inarticulate feedback does not. Very often, feedback has the last utterance of the previous speaker as its scope, but not always. An analysis of the scope of feedback behaviour in two corpora, the AMI corpus[1] and a French corpus of two-party route explanation dialogue collected at the University of Toulouse[2] Petukhova et al. (2011) shows that feedback mostly (in 61% of the cases) has the immediately preceding utterance as its scope.[3] Table 2 shows the percentage of feedback occurrences with a scope of 1-10 utterances or a much larger scope (namely the entire preceding dialogue), and the distance between the feedback and its scope. We see that around 80% of the feedback cases has its scope in the preceding 1-3 utterances.

1.4 Feedback studies and statistics

Feedback has been studied empirically for its forms, functions, and contexts of occurrence, e.g. by Allwood et al. (1993), Allwood & Cerrato (2003), Clark & Krych (2004), Petukhova & Bunt (2009b), Petukhova et al. (2011), and within the conversational analysis tradition notably by Drew (1997) and Drew & Heritage (1992).

[1] See `http://www.ami-project.org`

[2] For more information see Muller & Prévot (2003).

[3] In fact this percentage is higher, since distance was measured in terms of 'functional segment's, which are smaller than utterances. See Petukhova et al. (2011) for details and for the precise definition of distance.

scope	feedback	distance	feedback
1	54.1	0	61.0
2	9.8	1	8.8
3	7.7	2	9.3
4	1.1	3	4.9
5	3.9	4	2.7
6	2.8	5	2.2
7	1.1	6	2.2
8	0.2	7	1.1
9	0.0	8	0.8
$\geq$ 10, <600	14.9	10	0.5
>600	4.4	>20	1.6

Table 1: Feedback scope and distance

Table 2 shows the frequency of occurrence of explicit feedback acts in three different corpora, the AMI corpus, the Dutch DIAMOND corpus of telephone dialogues with a help desk[4], and the OVIS corpus of Dutch human-computer telephone dialogues.[5]

	AMI	DIAMOND	OVIS
Auto-Feedback	20.5	19.1	24.1
Allo-Feedback	0.7	3.8	39.2

Table 2: Frequency (percentage of functional segments) of feedback acts in AMI, DIAMOND, and OVIS corpora.

2 Feedback as dialogue acts

2.1 Dialogue acts

Communicative feedback can be described in terms of communicative actions, performed by a speaker in order to provide information to his addressee(s) or to elicit information from him/them about the processing of previous utterances. We analyse feedback behaviour therefore within a framework constructed around communicative actions used in dialogue, called *dialogue acts*. In this framework, called Dynamic Interpretation Theory (DIT), communicative behaviour is viewed as consisting of actions that are intended to change an addressee's information state in certain ways. Such a view, commonly known as the information-state update approach to the semantics of dialogue utterances, has widely been adopted

[4] See Geertzen et al. (2004)

[5] Corpus of dialogues over the telephone with the experimental Dutch public transportation information system. See `http://www.let.rug.nl/~vannoord/OVIS`.

for the analysis of spoken and multimodal dialogue (see e.g. Larsson & Traum, 2000). The DIT framework (Bunt, 1994; 2000) has been used in the construction of a comprehensive domain-independent dialogue act taxonomy, the DIT^{++} taxonomy.[6] This taxonomy has formed the basis of the recently established ISO standard 24617-2 for dialogue act annotation (ISO 24617-2:2012); see Bunt et al. (2010; 2012).

2.2 Communicative functions and dimensions

In the DIT framework communicative behaviour is analyzed as the performance of several parallel activities, such as pursuing a certain task or activity, providing and eliciting feedback, taking turns, and editing one's contributions. Each of these types of activity is called a *dimension*; in total 10 dimensions are defined: *Task, Auto-Feedback, Allo-Feedback, Turn Management, Time Management, Contact Management, Discourse Structuring, Own Communication Management, Partner Communication Management*, and *Social Obligations Management* (see Bunt, 2009; Petukhova & Bunt, 2009a) Dialogue acts are the actions that dialogue participants use to perform these activities. A dialogue act has as its main components a *semantic content*, which specifies the entities, relations, propositions, events, actions, etc. that the dialogue act is about, and a *communicative function*, that specifies how an addressee should use the semantic content to update his information state.

A distinctive feature of the DIT^{++} taxonomy is that it consists of two parts, the 'dimension-specific' functions that can be used only for a dialogue act in a specific dimension (such as Take Turn and Turn Release in the Turn Management dimension, Stalling in the Time Management dimension, and Self-Correction in the Own Communication Management dimension), and the 'general-purpose' functions, that can be used in any dimension, such as Inform, Question, Answer, Confirm, Offer, Request, Suggest.

Figure 1 shows the taxonomy of general-purposse communicative functions, which is shared by DIT^{++} and the ISO 24617-2 standard; Figure 2 shows the DIT^{++} taxonomy of dimension-specific communicative functions, of which the ISO 24617-2 standard uses a subset.

[6] See Bunt (2009) and http://dit.uvt.nl.

2.3 Feedback acts

Feedback acts can be formed in two ways: (a) by combining a general-purpose function (GPF) with a semantic content that refers to the processing of previous utterances; and (b) by using a dimension-specific feedback function (FSF). GPFs can be used to form an articulate feedback act, as illustrated by the examples in (9), where we see e.g. an Auto-Feedback Set-Question in (a), an Allo-Feedback Confirm in (c), and an Auto-Feedback Inform in (d).

Both articulate and inarticulate feedback can be specific or unspecific about a level of processing; Petukhova & Bunt (2009b) show for example that inarticulate positive feedback in the form of nodding can indicate whether it is concerned with understanding or with evaluation by the speed, the number, and the amplitude of the nods. But sometimes speakers do not commit to a level of processing, in which case a level-unspecific feedback act should be used to describe the behaviour.

In DIT^{++} five levels of processing are distinguished; ordered from 'low' to 'high', these are:

(8) attention
perception
interpretation
evaluation
execution

'Evaluation' should be understood here in relation to the information-state update approach and the requirement that information states at all times remain internally consistent. For example, the recipient of an inform act with a semantic content p knows that the speaker wants him to insert the information p in his information state. Before doing this, the recipient has to check whether p is consistent with his current state; the information p is therefore buffered in the 'pending context'. If the evaluation has a positive outcome, then the recipient can move on to the stage of execution, which is the highest level of processing of an input. For this example, execution would be that the recipient moves the content from the pending context into his information state. The examples in (9) illustrate the occurrence of feedback acts relating to each of the five levels of processing.

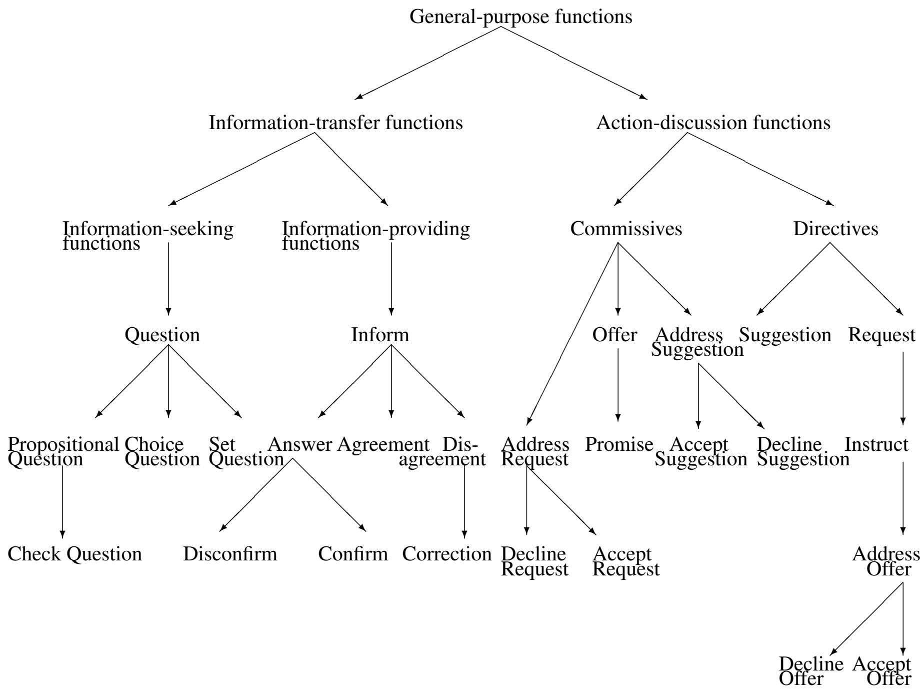

Figure 1: Dimension-speccfic communicative functions for feedback.

(9) a. Sorry, I wasn't listening. You were saying?

b. Between 11 and 1 you said?

c. A: Friday the 13th?
B: That's what I mean.

d. That's a good question.

e. A: To change the contrast first press F9.
B: Done.

The five levels of (8) have logical relationships; e.g., a message has to be perceived to some extent in order to be understood. These relations are the basis of entailments between feedback acts at different levels: a positive feedback act at one level logically entails positive feedback at lower levels, and a negative feedback act at one level entails negative feedback at higher levels. 'Positive' feedback means the utterance(s) concerned (or a dialogue act that they express) has been processed with sufficient success to not require a clarification or correction before moving on.

Moreover, the ordering of processing levels gives rise to conversational implicatures that derive from the Gricean principle of informativeness. If, for example, you did not understand well enough what was meant, then this is what you should report, rather than a perceptual problem. Therefore, positive feedback at one level implicates negative feedback at higher levels. For negative feedback it's the other way round.[7] This is summarized in Table 1.

polarity	*levels*	*relation*	*polarity*
positive	$L_i > L_j$	entailment	positive
positive	$L_i < L_j$	implicature	negative
negative	$L_i < L_j$	entailment	negative
negative	$L_i > L_j$	implicature	positive
elicitation	$L_i > L_j$	implicature	pos. allo-fb

Table 3: *Entailments and implicatures between feedback acts at different levels of processing (from Bunt, 2011b.)*

2.4 Dialogue act semantics

Bunt (2011a) formalizes communicative functions as specifications for updating an information state with a given content. This formalization has the form of a semantics for the Dialogue Act Markup Language (DiAML), defined as part of ISO standard 24617-2. In this language, a dialogue act is characterized by a sender, one or more addressees, a communicative function, a dimension, and possibly additional specifications of certainty, conditionality, or sentiment (so-called 'qualifiers'), and relations with

[7] An expression such as *"What are you saying?"* can be used to express e.g. astonishment or disbelief, rather than a perceptual problem; this is typically indicated by the use of prosody and accompanying facial expression and gestures.

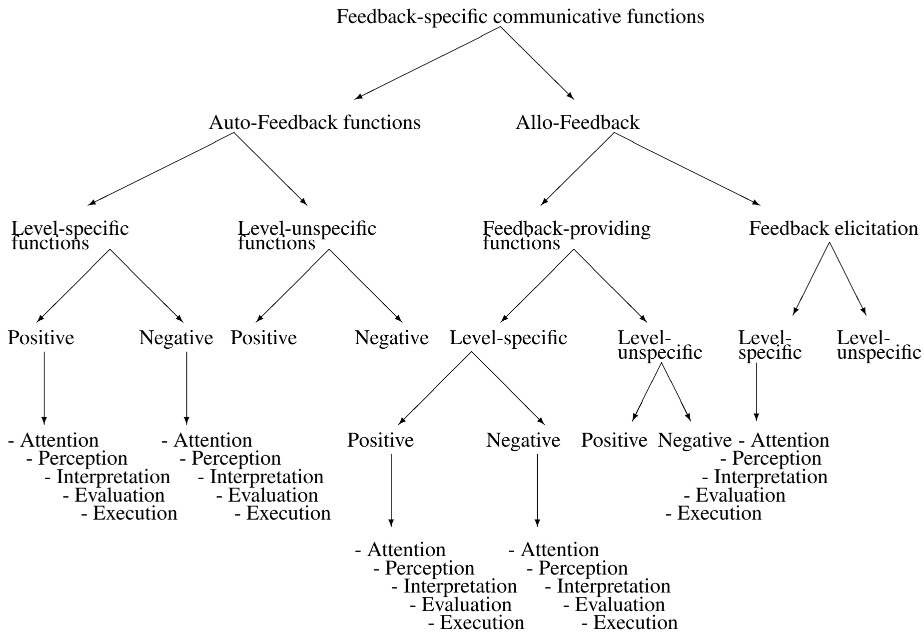

Figure 2: Dimension-speccfic communicative functions for feedback.

other dialogue acts. A specification of values for each of these parameterss gives a function that can be applied to a semantic content, resulting in an information state update operation.

3 The semantics of feedback acts

3.1 Feedback-specific communicative functions

Figure 3 shows the dimension-specific communicative functions of the DIT taxonomy for the dimensions of Auto- and Allo-Feedback. For auto-feedback there are five level-specific positive and five negative functions; likewise for allo-feedback, which has additionally five level-specific functions for feedback elicitation. In addition there are four level-unspecific communicative functions.

3.2 Semantic primitives

An analysis of the definitions[8] of the communicative functions of Fig. 1 and Fig. 2 shows that a formal description of the update effects of dialogue acts with a GPF (general-purpose communicative function) requires a number of general concepts, such as *believes that, knows value of, has goal, is able to do, is willing to do*, and that for describing the update semantics of dimension-specific communicative functions a number of dimension-specific primitives are needed. Auto- and allo-feedback acts require the following primitive predicates: **Attended, Perceived, Understood, Accepted,** and **Executed**.

3.3 Level-specific feedback acts

The semantics of level-specific feedback acts, providing information about the success of processing at level L_i, expresses that the sender of the feedback wants the addressee to know in the case of positive feedback that the utterances within its scope were successfully processed at that level; in the negative case that a processing problem occurred at that level; and in the case of feedback elicitation that the sender wants to know whether the addressee's processing was successful at that level.

The interpretation of a positive feedback act is that an addressee's information state is updated with the information that speaker wants the addressee(s) to know that the utterances in its scope were successfully processed at level L_i. This can be formalized by means of combinations of elementary update schemes in order to add two relevant beliefs to the pending context part of an addressee's information state: (1) that the speaker believes he successfully processed its content at level L_i; (2) that he wants

[8]The definitions can be found in ISO 24617-2:2012 and on http://dit.uvt.nl.

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the addressee to know that.

For example, a positive feedback act at the level of understanding, like in (6a), would be interpreted as the combination, defined in (10a), of the elementary update schemes U_{33} and U_{53} (defined in Table 5). Applied to example (6a), the update effects are that B's information about A's processing (i.e. B's pending context B'_{PC}), is extended (indicated by the symbol $=+$) to include the information that A believes he heard B say *"We meet again next Friday"*, and that A wants B to know that.

(10) a. F(AutoPerceptionPositive) $= \lambda X.\lambda Y.\lambda z. U_{33}(X,Y,z) \sqcup U_{53}(X,Y,z)$

b. B'_{PC} =+ **Bel**(B, **Want**(A, **Bel**(B, **Understood** (A, 'we meet again next friday'))))
B'_{PC} =+ **Bel**(B, **Bel**(A, **Understood**(A,'we meet again next friday')))

Table 4 lists the semantics of 5 of the 25 level-specific communicative functions of the DIT^{++} taxonomy, one for each level of processing; Table 5 shows the elementary update schemes involved. The semantics of the remaining (20) functions and update schemes can be extrapolated from these tables. For example, a positive auto-feedback act by A at the level of evaluation, addressed to B, with content c_0, updates B's pending context (B'_{PC}) using the update schemes U_{34} and U_{54} as follows:

B'_{PC} =+ **Bel**(B, **Bel**(A, **Accepted**(X, c_0))) $\sqcup$
B'_{PC} =+ **Bel**(B, **Want**(A, **Bel**(B, **Accepted** (A, c_0)))

3.4 Level-unspecific feedback acts

For determining the semantics of a feedback act which is underspecified for a level of processing, a maximally cautious approach would be to assume level-unspecific feedback to apply at the lowest level of processing, i.e. positive feedback as signalling attention without making any assumptions about signal recognition, understanding, and higher processing, and negative feedback as signalling an attention problem, and therefore also problems at all higher levels of processing. This does not seem realistic, however; level-unspecific positive feedback signals like *"yes"*, *"okay"*, and nodding typically signal more than just paying attention, and negative signals do not just signal a problem at the level of attention, but rather at a higher level. We propose to determine the levels of processing covered by level-unspecific feedback acts empirically.

To this end, we analyzed the feedback level interpretations in data obtained in an annotation experiment, originally performed in order to assess inter-annotator agreement among naive annotators using the DIT^{++} annotation scheme (see Geertzen et al., 2007). The experiment showed that annotators often found it difficult to choose a level of processing when annotating flevel-unspecific eedback acts. This explains why agreement scores were found for auto- and allo-feedback of .36 and .33, respectively, which are much lower than those for other dimensions (average .61). This motivated the designers of the ISO 24617-2 annotation scheme to collapse the level-specific feedback functions of DIT^{++} into the level-unspecific communicative functions Auto-Positive, Auto-Negative, Allo-Positive, Allo-Negative, and Feedback Elicitation (which were subsequently also added to the DIT^{++} taxonomy).

We analyzed the annotations produced in this experiment for the number of times annotators assigned a particular level to a feedback act of which the level was not clearly expressed in linguistic and/or nonverbal features of the behaviour, and calculated the number of times each level was chosen in those cases where not all four annotators agreed. The results are shown in Table 4 for human-human dialogues from the Map Task corpus and for human-computer dialogues from the OVIS corpus.

The table shows that level-unspecific feedback is almost never interpreted as applying at the level of attention. For the rest, the results are very different. In the human-human condition positive auto- and allo-feedback are both interpreted mostly as applying to evaluation or execution, whereas in the human-computer dialogues most feedback acts concerned perception or understanding. The latter result is directly related to the deficiencies in automatic speech recognition, and to some degree also to the machine's limited understanding of the user.

Since the interpretation of level-unspecific feedback acts depends on the setting in which the dialogue occurs, we propose to introduce a predicate **SuccessProcessing** that represents successful processing, whose interpretation depends on the dialogue setting. For human-human dialogue (the MT

F(AutoAttentionPositive)	=	$\lambda X.\lambda Y.\lambda z.U_{31}(X,Y,z) \sqcup U_{51}((X,Y,z))$
F(AlloPerceptionNegative)	=	$\lambda X.\lambda Y.\lambda z.U_{37}((X,Y,z)) \sqcup U_{57}((X,Y,z))$
F(AutoInterpretationPositive)	=	$\lambda X.\lambda Y.\lambda z.U_{33}(X,Y,z) \sqcup U_{53}((X,Y,z))$
F(AutoEvaluationPositive)	=	$\lambda X.\lambda Y.\lambda z.U_{34}(X,Y,z) \sqcup U_{54}((X,Y,z))$
F(ExecutionElicitation)	=	$\lambda X.\lambda Y.\lambda z.U_{75}(X,Y,z)$
F(AutoPositive)	=	$\lambda X.\lambda Y.\lambda D_i.\lambda z.U_{39}(X,Y,z) \sqcup U_{59}(X,Y,z)$

Table 4: Semantics of feedback functions (selection)

$U_{31}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Want**(X, **Bel**(Y, **Attended**(X,z))))
$U_{33}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Want**(X, **Bel**(Y, **Understood**(X,z))))
$U_{34}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Want**(X, **Bel**(Y, **Accepted**(X,z))))
$U_{37}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Want**(X, **Bel**(Y, **Perception-Problem**(Y,z))))
$U_{39}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Want**(X, **Bel**(Y, **SuccessProcessing**(X,z))))
$U_{51}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Bel**(X, **Attended**(X,z))))
$U_{53}(X,Y,D_i,z)$	Y'_{PC} =+ **Bel**(Y, **Bel**(X, **Understood**(X,z))))
$U_{54}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Bel**(X, **Accepted**(X,z))))
$U_{57}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Bel**(X, **Perception-Problem**(X,z))))
$U_{59}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Bel**(X, **SuccessProcessing**(X,z))))
$U_{75}(X,Y,z)$:	Y'_{PC} =+ **Bel**(Y, **Want**(X, **Know-if**(X, **Execution-Problem**(Y,z))))

Table 5: Elementary update schemes used in the semantics of auto- and allo-feedback functions.

condition), according to Table 6 this predicate can be interpreted as representing successful processing at the level of understanding or higher, i.e., as signalling successful understanding and possibly also successful 'higher' processing. Negative feedback would be interpreted as complementary to positive feedback.

So a positive level-unspecific feedback act, with the communicative function AutoPositive, like the one contributed by B in (11a), would (according to Table 4) be interpreted by the combination of elementary update schemes U_{39} and U_{59}, defined in Table 5.

(11) a. A: I said five buttons max.
B: Okay.

b. F(AutoPositive) = $\lambda X.\lambda Y.\lambda z.U_{59}(X,Y,z) \sqcup U_{39}(X,Y,z)$

c. B'_{PC} =+ **Bel**(B, **Want**(A, **Bel**(B, **SuccessProcessing** (A, 'I said five buttons max'))))
B'_{PC} =+ **Bel**(B, **Bel**(A, **SuccessProcessing**(A, 'I said five buttons max')))

Interpreting the predicate **SuccessProcessing** in certain conditions as "well understood and possibly also accepted and executed successfully" may seem to mean that level-unspecific feedback is in fact interpreted as level-*specific* feedback at the level of understanding, but there is a subtle difference in implicatures: level-specific positive feedback at the level of understanding implicates negative feedback at the levels of evaluation and execution, but in the case of level-unspecific feedback these implicatures do not arise. Similarly for implicated negative feedback.

3.5 Entailed and implicated feedback

Feedback may be entailed or implicated by non-feedback acts. Example (1) illustrated the occurrence of *implicated* positive feedback, which is at the highest level of processing (the answer that the thanking applies to is not just *understood*, but also *accepted* and *adopted*). Negative feedback may be implicated e.g. when the speaker jumps abruptly to a new topic, which may carry the suggestion that the previous topic was closed in an unsatisfactory manner; in such a case it is not evident at which level of processing a problem occurred.

Positive feedback is *entailed* by all responsive dialogue acts such as answers, confirms and disconfirms; acceptance or rejection of offers, suggestions, or requests; return greetings, accept apologies, and several others.

(12) a. A: So, um, how many buttons do you suggest?
B: I said five max.

feedback	*auto-positive*		*auto-negative*		*allo-positive*		*allo-negative*	
level	MT	OV	MT	OV	MT	OV	fMT	OV
attention	3	0	0	0	0	0	0	0
perception	0	28	0	6	1	3	0	9
interpretation	4	20	0	6	2	0	0	14
evaluation	32	0	1	0	8	0	0	6
execution	34	0	1	8	12	0	0	0

Table 6: Interpretation levels (in percentages) in Map Task (MT) dialogues and OVIS (OV) dialogues)

b. A: Pete, could you start the presentation?
   B: Sure.
c. A: Sorry, we have no information about that.
   B: No problem.

In all these cases it can be argued that the responsive dialogue act is only possible if the 'antecedent' dialogue act was sufficiently well understood, was accepted, and was 'executed' successfully. This illustrates that entailed feedback is in general at the highest level of processing, that of execution, and therefore at all levels.

In sum, implied positive feedback, wether entailed or implicated, is positive at all levels of processing. Implied negative feedback is virtually never about failed attention or perception, but rather about understanding, evaluation, or execution.

4 Applications

The study of the forms, functions, and semantics of feedback has both theoretical and practical applications.

Theoretically, a good understanding of feedback is indispensable for a good understanding of language in interaction, and has been studied in relation to natural language understanding e.g. by Ginzburg (1994), Ginzburg & Cooper (2004), Purver et al., (2001). Feedback plays a crucial role in processes of grounding (the establishment of common ground among dialogue participants), and has as such been studied e.g. by Traum (1994), Clark (1996) and Bunt et al. (2007). The semantics of feedback plays a role in some of these studies, but often not in an explicit and certainly not in a complete way; for example, allo-feedback has not been considered in any of these studies with the exception of Bunt (1999).

Sophisticated interactive automatic systems should be able to understand and to generate appropriate forms of feedback at appropriate points in the interaction. This application of models of feedback has been investigated e.g. by Van Dam (2006), for the design of graphical user interfaces; for designing the PARADIME dialogue manager of the IMIX information extraction system (Keizer et al., 2011), for the design of the multimodal DENK dialogue system (Ahn et al., 1995) and for the GoDiS dialogue system by Larsson et al. (2000).

5 Conclusions

In this paper we have shown that a formal and computational semantics in terms of information state updates can be given for a wide range of forms and functions of feedback, including auto- and allo-feedback (including feedback elicitation), which both can be positive or negative, articulate and inarticulate, specific for a particular level of processing or level-unspecific, and entailed or implicated.

For feedback acts which are unspecific regarding a level of processing, we proposed to use an empirically determined level of success, which appears to be different for human-computer dialogue than for natural human dialogue.

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