Towards a Failure-driven Mechanism for Discourse Planning: a Characterization of Learning Impairments

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ABSTRACT

In the process of generating discourse, speakers generate utterances which directly achieve the communicative goal of conveying an information item to a hearer, and they also generate utterances which prevent the disruption of correct beliefs maintained by a hearer or the inception of incorrect beliefs. In this paper, we propose a representation scheme which supports a discourse planning mechanism that exhibits both behaviors. Our representation is based on a characterization of commonly occurring impairments to the knowledge acquisition process in terms of a model of a hearer's beliefs. As a testbed of these ideas, a discourse planner called WISHFUL is being implemented in the domain of high-school algebra.

INTRODUCTION

In the process of generating discourse, speakers generate utterances which directly achieve the communicative goal of conveying an information item to a hearer†, and they also generate utterances which prevent the disruption of correct beliefs or the inception of incorrect beliefs due to inferences performed by a hearer.

Goal-based discourse planning systems constitute a significant trend in the discourse planning effort. In these systems, a communicative goal, such as *KNOW*(*item*), is posted, and then a plan which includes speech acts as actions is formulated to attain this goal. If, according to a model of a hearer's beliefs, a precondition to an action is not satisfied, then it is posted as a subgoal (Appelt 1982, Hovy 1988, Moore and Swartout 1989). In particular, in systems developed by Hovy and by Moore and Swartout, generated discourse plans include rhetorical relations, such as Elaboration and Evidence, from Rhetorical Structure Theory (Mann and Thompson 1987). Goal-based discourse planners model successfully the first aspect of human discourse generation. However, they fail to account for rhetorical devices such as Revisions of previous material [''*In chapter 7, we saw how to factorize expressions ...* ''] and Contradictions to erroneous beliefs or inferences [''Koalas are marsupials, *not bears*''], which address beliefs that are indirectly affected by the discourse. These rhetorical devices are accounted for by discourse generation systems which apply forward reasoning (Zukerman 1990a). Thus, in order to model both types of human discourse generation strategies and to generate a range of rhetorical devices which supports competent discourse, we need to apply both forward and backward reasoning.

In this paper, we propose a uniform representation formalism which supports discourse planning by means of both types of reasoning processes, and we motivate our representation by means of a simple discourse planner which applies both reasoning processes in sequence. Our formalism relies on a characterization of impairments to the knowledge acquisition process, such as Confusion, Lack of Understanding and Loss of Interest, which is based on a model of a hearer's beliefs.

† The terms speaker/writer and hearer/listener/reader are used interchangeably in this paper.

In the following section, we briefly discuss a model of a listener's beliefs capable of representing uncertain beliefs and predicting inferences commonly drawn in a knowledge acquisition setting. Next, we describe a simple discourse planner which applies both forward and backward reasoning. We then present our characterization of impairments, and demonstrate its application in discourse planning.

NETWORK MODEL OF A LISTENER'S BELIEFS

In order to address beliefs presumably entertained by a particular listener, we maintain an epistemological model which represents a listener's beliefs as a result of direct and indirect inferences drawn from presented material (Zukerman and Cheong 1988, Zukerman 1990a).

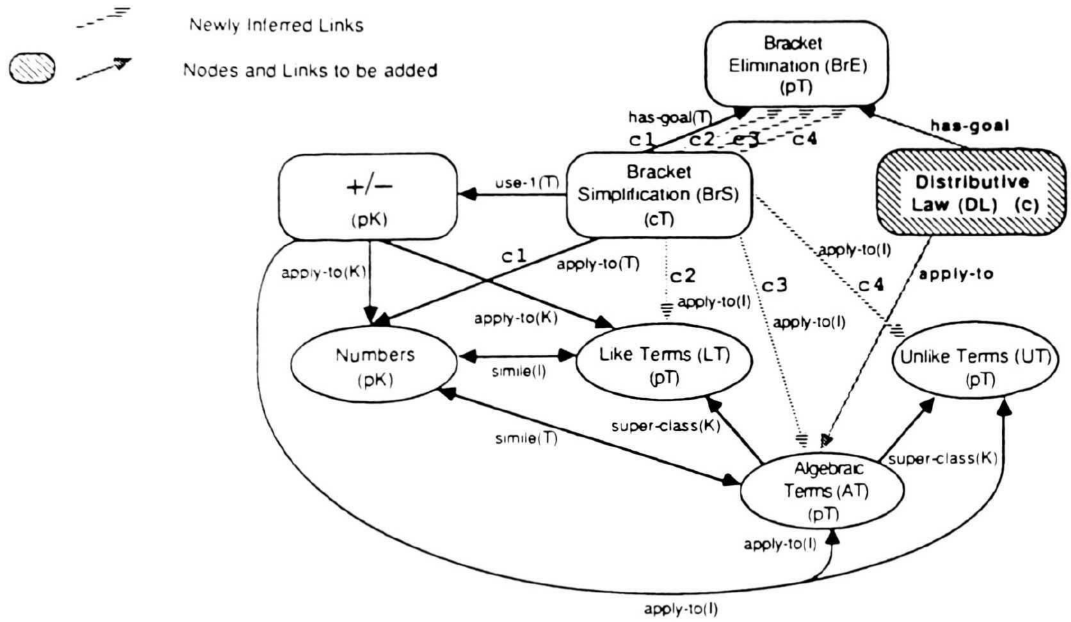

Fig. 1: Network Model of a Listener's Beliefs in High-School Algebra†

We represent a listener's beliefs by means of a network whose nodes contain individual information items and whose links contain the relationships between the nodes (see Figure 1). The links in the network are labeled according to the manner in which they were acquired, i.e., they can either be Inferred, Told or previously Known, where Inferred links are generated by means of generally applicable *Common-sense Inference Rules*. In addition, each link is accompanied by a *Measure of Belief (MB)* between -1 and 1, akin to Certainty Factors (Buchanan and Shortliffe 1985), which represents a user's level of expertise. The information in the network is represented at a level of detail which is consistent with the level of expertise required to learn the subject at hand, i.e., a simple and well-known concept is represented by a p-node (primitive), whereas a relatively new or complex concept is represented by a c-node (complex) which has other nodes as constituents. Like links, nodes may be Inferred, Told or previously Known, and each node has a *Degree of Expertise (DE)* between 0 and 1. The DE of a c-node is a function of the DEs and MBs of its constituent nodes and links, respectively. In this paper, we focus on technical domains, where the transmitted information typically pertains to *procedures*, *objects* and *goals*. Since one procedure will often achieve different goals when applied to different objects, we define a *context* as a triple composed of a procedure, an object to which it is applied, and the goal accomplished by this procedure when applied to this object (labeled c1-c4 in Figure 1).

† In the actual network each link may have a counterpart representing the inverse relationship. However, for clarity of presentation, only links which are relevant to our discussion are shown here.

Our inference mechanism generates plausible inferences from links in the network by means of generally applicable Common-sense Inference Rules which portray reasoning activities such as generalization, specialization and similarity-based inference (see Figure 2). These rules are inspired by rule adaptations commonly performed by students which were studied by Matz (1982), Brown and Van Lehn (1980), Van Lehn (1983) and Sleeman (1984). In order to account for the deductive abilities of a particular type of listener, we annotate each rule with a measure of uncertainty, denoted ρ, which represents a listener's belief in the validity of a conclusion given that the evidence is certain. This measure resembles the rule strength used in ACT* (Anderson 1983).

R1
; *If procedure* $PROC_a$ *initially uses a given set of procedures and these procedures apply to*
; *disjoint parts of a given object* OBJ_m *then, with likelihood* ρ_1, $PROC_a$ *is applicable to* OBJ_m
IF [for $i=1, \cdots, n$ $\exists$ a use-1 link between $PROC_a$ and $PROC_i$ with MB k_{ai}
AND for $i=1, \cdots, n$ $\exists$ an apply-to link between $PROC_i$ and OBJ_m with MB k_{im}]
THEN (with certainty ρ_1)
Add an apply-to link of type I between $PROC_a$ and OBJ_m with MB $k_{am}=\frac{\rho_1}{n}\sum_{i=1}^{n} k_{ai} k_{im}$

Fig. 2: Sample Inference Rule

THE BASIC MECHANISM

As stated above, in a knowledge acquisition setting, a speaker's communicative goal not only pertains to the acquisition of a particular item of knowledge, but also to inferences a hearer is likely to draw and to other beliefs held by the hearer. Thus, given an *Intended Message (IM)* to be conveyed to a hearer, the following tasks must be performed:

1. Generate *Peripheral RDs*, such as Contradictions and Revisions, which are related to the IM but are not directly instrumental to its acquisition.
2. Generate *Supportive RDs*, such as Causal Explanations, Examples and Descriptions, which are directly instrumental to the attainment of the goal $KNOW(m)$, $\forall m \in$ *{IM, Peripheral RDs}*.
3. Sort the IM and the proposed RDs according to rhetorical considerations.

In general, these tasks should not be performed in strict sequence, but should be interleaved, since they affect each other's results. However, there are conditions under which the sequential execution of these tasks leads to coherent text (Zukerman 1990b). Hence, a two-stage discourse planner which generates Peripheral and Supportive RDs sequentially will suffice in order to illustrate the application of our characterization of learning impairments.

In the first stage, we apply forward reasoning to evaluate the impact of an IM on a listener's beliefs, and generate Peripheral RDs to counteract learning impairments which are likely to take place. To this effect, we temporarily assume that the goal *KNOW(m)* for $m \in$ *{IM, Peripheral RDs}* can be attained by merely stating the message in question (this assumption is eliminated in the second step). This stage is executed as follows: initially, a network representing the IM is added to the network representing a listener's beliefs (see Figure 1). Next, a *Recognition* mechanism uses a characterization of learning impairments to anticipate whether the IM is likely to cause an impairment. If this is the case, a *Selection* procedure suggests a preventive Peripheral RD based on this impairment. A *Propagation* mechanism then performs forward reasoning by activating Common-sense Inference Rules to draw inferences from the proposed RD and the IM. The Recognition-Selection-Propagation cycle is repeated with respect to the newly drawn inferences until no impairments remain, i.e., no Peripheral RDs are proposed. This mechanism accounts for the presence of the Contradiction (in italics) in the sentence

''Pandas are bears, *but red pandas are not,*'' which prevents Mislearning due to an erroneous inference from the first part of the text. (A detailed description of this procedure appears in [Zukerman 1990a].)

In the second stage, backward reasoning is applied to generate Supportive RDs which fulfill the preconditions for the acquisition of each of the messages proposed in the first stage. Since the fulfillment of the preconditions to discourse actions (i.e., speech acts) is equivalent to the avoidance of learning impairments, a characterization of learning impairments may be used to determine Supportive RDs. This procedure accounts for the generation of a Causal Explanation such as ''*they are raccoons*'' to support the Contradiction in the above example. In the remainder of this paper we focus on our characterization of learning impairments based on our model of a hearer's beliefs, and demonstrate its use in discourse planning.

CHARACTERIZING KNOWLEDGE ACQUISITION IMPAIRMENTS

We distinguish between three main types of impairments which are responsible for a listener's failure to acquire the beliefs intended by the speaker from the presented information. Our distinction is based on the role of these impairments in the knowledge acquisition process, namely: *Comprehension-related*, *Affect-related*† and *Inference-related.* Comprehension-related impairments directly inhibit the acquisition of a message, while Affect- and Inference-related impairments inhibit the acquisition of a message through their effect on related beliefs held by a listener. Thus, the recognition and invalidation of possible Comprehension-related impairments is performed in the second stage of the above discourse planning procedure, yielding Supportive RDs; while the recognition and invalidation of the other learning impairments is performed in the first stage, generating Peripheral RDs.

Affect-related Impairments

Affect-related impairments occur when a hearer experiences adverse affective responses due to a conflict between the presented information and his/her existing beliefs. These conflicts inhibit the hearer's acquisition of this information even though s/he may understand it. In a knowledge acquisition setting, two common Affect-related impairments are *Confusion* and *Loss of Interest.*

Confusion occurs when an inference decreases significantly a listener's confidence in a previous belief, i.e., the absolute value of the MB of a link in a network representing a hearer's beliefs is significantly lowered due to the effect of an inference. For instance, upon reading the statement ''One cannot always add Algebraic Terms,'' which yields a negative value for the MB of the link [+/– apply-to AT] in the network in Figure 1, a listener may erroneously infer that one cannot always add Like Algebraic Terms, in direct contradiction with his/her previous belief. The invalidation of Confusion caused by the effect of an incorrect inference on a correct link is performed by a Revision of this link, e.g., ''but Like Terms can always be added''; while the invalidation of Confusion due to the effect of a correct inference on an incorrect link is performed by a Contradiction of this link.

Loss of Interest occurs when a listener who is initially motivated to acquire knowledge is presented with an IM s/he considers redundant. In terms of our model, this takes place if there exists a node *B* which *subsumes* a new node *A*, i.e., new distinguishing links incident upon *A* are connected to the same nodes and have MBs of compatible magnitude and sign as the corresponding links incident upon *B*. This situation is illustrated in Figure 1, where we try to add the node ODL, representing distributive law, and the links [DL apply-to AT] and [DL has-goal BrE] to the network representing a listener's beliefs. However, the existence of the erroneous link [BrS apply-to AT] makes the node BrS equivalent to DL, thereby rendering the new procedure redundant and causing Loss of Interest. If Loss of Interest is caused by an incorrect link, it is invalidated by a Contradiction of this link, e.g., ''One can not always simplify bracketed algebraic expressions''; whereas if all the links participating in this

† The term *affect* is used in this paper in the sense of *emotions.*

impairment are correct, the generation of a Motivation which adds new links to the message to be transferred is called for. Clearly, Loss of Interest may also be caused by boredom or by lack of understanding. However, in this case, Loss of Interest is a secondary learning impairment which results from other impairments.

Inference-related Impairments

Inference-related impairments take place when a hearer has failed to realize the implications intended by a speaker. That is, inferences which pertain to beliefs that the speaker intends the hearer to hold upon completion of the discourse produce either correct but weak beliefs or incorrect beliefs. These inferences may either affect previously existing beliefs or may be responsible for the inception of new beliefs. Inference-related impairments which are common in a knowledge acquisition setting are *Mislearning, Insufficient Learning* and *Insignificant Change* in a listener's knowledge status. A characterization of these impairments must take into consideration the difference between a listener's level of expertise with respect to a link and a level of expertise considered satisfactory.

Mislearning takes place when an erroneous belief with a relatively high degree of confidence is produced by an incorrect inference drawn by a listener, i.e., the link in question acquires a high MB with a wrong sign. This impairment is invalidated by a Contradiction of the inference.

Insufficient Learning occurs when a correct inference yields a correct belief with a relatively high MB, but which still falls short of a desired MB representative of proficiency. This impairment is invalidated by a Revision of the inference.

Finally, an ***Insignificant Change*** in a listener's knowledge status occurs when an inference produces a rather inconsequential change in a link with an MB representative of insufficient proficiency. The invalidation of this impairment in a link with a relatively high MB is performed by a Revision of the link, if it is correct, and a Contradiction, otherwise. In a link with a low MB, this impairment is considered equivalent to ignorance, and is invalidated accordingly.

The immediate invalidation of Affect-related impairments is essential for the smooth continuation of the knowledge acquisition process, since their persistence diverts a listener's mental resources from the task of acquiring further knowledge. On the other hand, the invalidation of Inference-related impairments with respect to links which are removed from the main focus of the discourse may be postponed if didactic or stylistic constraints prohibit the invalidation of all the recognized impairments.

Comprehension-related Impairments

Different Supportive RDs may accomplish the same function with respect to the comprehension process, e.g., a concept may be created in memory by means of a Description or an Analogy. Further, one Supportive RDs may perform a number of functions, e.g., a Description may be used to create a new concept or to identify a known concept. Therefore, we distinguish between three types of Supportive RDs according to their function rather than their structure, namely *Creative, Indicative* and *Explanatory*. Creative RDs are generated to build or reinforce a mental representation of a concept, Indicative RDs are generated to identify an existing concept in memory, and Explanatory RDs are produced to foster belief in a proposition. The Comprehension-related impairments characterized below determine the type of a Supportive RD to be generated.

In order to characterize Comprehension-related impairments, we have found it convenient to separate the comprehension process into three phases: (1) *Access* of the concepts in memory intended by the speaker, (2) *Construction* of a representation in memory of the presented information, and (3) *Acceptance* of the correctness of the presented information. We postulate that in a knowledge acquisition setting, if all these phases are successfully completed, then a message will be understood. In other types of settings, such as a task oriented setting, the third phase is desirable but not essential.

In order to complete the Access phase, the following subgoals must be satisfied: (1) Connection — the hearer must reconcile a referring expression used by a speaker with a node in memory which is intended by the speaker, and (2) Content — the goal *KNOW* must be fulfilled with respect to the intended node. A Content-related impairment may occur in conjunction with a Connection-related impairment, thereby requiring the generation of Supportive RDs which satisfy both subgoals. *Lack of Connection* and *Misunderstanding* are Connection-related impairments, and *Lack of Understanding* and *Insufficient Understanding* are Content-related impairments. These impairments define the preconditions to the attainment of the subgoals of the Access phase, and are characterized in terms of our network model as follows†.

Lack of Connection occurs when one of the following conditions is satisfied: (1) a lexical item used by a speaker to refer to an intended node does not exist in the network which represents a listener's beliefs, i.e., the listener is unfamiliar with the terminology used by the speaker, (2) the lexical item exists in the network, but it is not connected to a concept, (3) it is weakly connected to the intended node (and no other node), or (4) it is connected to the intended node (and no other node), but this node is not primed in the network, i.e., it is outside the listener's *attentional state*‡. The last condition may occur when the discourse diverges both in time and place from the intended node, inhibiting a listener's ability to access it, even if its name has been mentioned. The invalidation of this impairment is performed by means of an Indicative RD, such as the Instantiation in the text "Like Algebraic Terms, e.g., $2x+3x$."

Misunderstanding occurs when a lexical item mentioned by a speaker is connected to a node which is not the intended node. This may be due to a true mis-connection or due to the fact that there is more than one concept with the same name, and the 'wrong' one is primed. A common example of the latter case is a scenario where two people are talking about another person, let's call her Mary, but each participant in the dialogue has a different Mary in mind. Like Lack of Understanding, this impairment is invalidated by means of an Indicative RD, such as "Mary Smith, not Jones."

Lack of Understanding takes place when there does not exist in the network representing a hearer's beliefs a node which corresponds to an intended concept. It entails a connection-related impairment, since a lexical item cannot point to an absent node. This impairment is invalidated by a Creative RD.

Finally, ***Insufficient Understanding*** takes place when there exists a node which corresponds to an intended concept, but the Degree of Expertise associated with this node indicates lack of proficiency. This impairment may occur in conjunction with a connection-related impairment or by itself. It is also invalidated by a Creative RD, but emphasis is placed on addressing missing or erroneous constituents of the node in question, rather than the entire concept. For example, "In completion to square, *you add and subtract* $(b/2a)^2$."

If a lexical item is used by a speaker to refer to a concept, the recognition of an impairment calls for the generation of an *Identification* which associates a proposed Supportive RD with this name, e.g., "A *crook* is a shepherd's staff." This may result in other impairments, such as Confusion or Mislearning, if the intended node is connected (either correctly or incorrectly) to another lexical item, i.e., it is identified with another name, or if the lexical item is connected (either correctly or incorrectly) to another node, i.e., there is more than one node with the same name. Both cases call for the generation of a Revision of the link in question, if it is correct, and a Contradiction, otherwise. In the above example, an impairment may take place if the hearer associates the lexical item *crook* with the concept *criminal.* If a speaker did not use a lexical item, Lack of Connection takes place, calling for the generation of an Indicative RD to enable a listener to access the node in question. In addition, a Creative RD may be required if the listener's expertise with respect to this concept is insufficient.

† We assume that the meaning of links, e.g., apply-to and subclass, is understood by a listener, and concentrate on nodes as possible sources of impairments.

‡ The term *attentional state* is due to Grosz and Sidner (1986).

At present, we recognize two preconditions for a ***Construction-related Impairment*** with respect to a given message: (1) the recognition of a Content-related impairment in the Access phase of the comprehension of this message, or (2) a low MB in the links between the nodes in this message or between the constituents of these nodes. The first condition indicates that the hearer is unfamiliar with the concepts themselves, and, hence, is likely to be unfamiliar with the way they relate to each other. It may be invalidated by forcing Instantiations in Creative RDs proposed during the Access phase. The second condition indicates that although the listener may be familiar with the concepts in isolation, s/he is not proficient with respect to the way they relate to each other. This condition may be invalidated by means of Creative RDs with Instantiations with respect to the context at hand.

Finally, we recognize two preconditions whose satisfaction anticipates an ***Acceptance-related Impairment*** with respect to a given message: (1) the application of Common-sense Inference Rules to links in the network which are close to the link representing this message yields an MB for this link which indicates insufficient proficiency, or (2) there exists at least one link which has an MB indicative of an erroneous belief and is related by means of a Common-sense Inference Rule to the link representing the message in question. The first condition stipulates that the combination of the beliefs held by a listener which are related to the belief to be acquired fails to adequately explain the correctness of this belief, whereas the second condition stipulates that it is sufficient to have one belief which undermines the belief to be acquired, in order to anticipate an acceptance failure. Impairments in the Acceptance phase may be invalidated by generating Explanatory RDs, where the links targeted by these RDs are the ones with the lowest MBs. For instance, in the sample network in Figure 1, the Contradiction ''Bracket simplification does not always apply to Algebraic Terms'' requires a Causal Explanation such as ''because you cannot always add Algebraic Terms,'' if the erroneous link [+/– apply-to AT] has a positive MB. The application of rule R1 in Figure 2 on this link and the link [BrS use-1 +/–] results in the link [BrS apply-to AT], thereby undermining a hearer's belief in the Contradiction.

A WORKED EXAMPLE

In this section, we briefly describe a possible behavior of our discourse planning procedure when teaching a student the distributive law. This situation is represented by the incorporation of the message [DL apply-to AT has-goal BrE], depicted by the shaded node and links in Figure 1, to the rest of the network in Figure 1. The result of this process is summarized in Table 1.

Table 1: RDs Proposed for the Intended Message [DL apply-to AT has-goal BrE]

RD Type	*RD Contents*	*Possible Text*
Revision *Identification* *Instantiation*	**[BrS apply-to LT has-goal BrE]** (BrS, 'bracket simplification') (BrS apply-to LT)	We can always eliminate brackets in like terms by applying bracket simplification. E.g., $2(5x+3x) = 2\times 8x = 16x$.
Contradiction *Causality*	**[BrS ¬apply-to AT]** (+/– ¬apply-to AT)	However, we cannot do this for all algebraic terms, because we cannot always add algebraic terms.
Intended Message *Identification* *Description* *Instantiation*	**[DL apply-to AT has-goal BrE]** (DL, 'distributive law') (DL) (DL apply-to AT)	In algebra, we can eliminate brackets by applying distributive law: We multiply each term inside the brackets by the term outside the brackets. For example, $2(x+y) = 2x + 2y$.

As stated above, in the forward reasoning stage, Loss of Interest is recognized due to the incorrect link [BrS apply-to AT], prompting the generation of a Contradiction of this link. The propagation of inferences from this RD cause Confusion in the correct link [BrS apply-to LT], calling for the generation of a Revision of this link. Since no further impairments are recognized in this stage, we proceed to the backward reasoning stage. During the Access phase, we recognize Lack of Understanding with respect to the new concept *distributive law*, and Lack of Connection with respect to the concepts *bracket simplification* and *Like Terms*. The first of these impairments is invalidated by means of a Creative RD, such as a Description, and the rest by means of an Indicative RD, say, an Instantiation. Next, during the Construction phase, an impairment may be detected with respect to the application of distributive law to Algebraic Terms, requiring an Instantiation to complement the Description. Finally, in the Acceptance phase, an impairment may be recognized with respect to the Contradiction, calling for a Causal Explanation, as explained above.

CONCLUSION

This paper offers a discourse planning paradigm based on a characterization of impairments to the knowledge acquisition process in terms of a model of a hearer's beliefs. Our characterization provides a parsimonious representation of the preconditions for the fulfillment of a communicative goal, and it supports both backward and forward reasoning in discourse planning. This characterization requires a model of a hearer's beliefs which represents uncertain beliefs and supports the generation of inferences. At present, the forward reasoning process has been implemented with respect to the network in Figure 1, producing Peripheral RDs which are consistent with those appearing in naturally occurring texts.

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