Computational Perspectives on Discourse and Dialogue

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1 Introduction

Computational work on discourse and dialogue reflects the two general aims of Natural Language Processing:

- that of modelling human understanding and generation of Natural Language in terms of a system of computational processes. Work in this area is usually called *Computational Linguistics*.
- that of enabling computers to analyze and generate Natural Language in order to provide a useful service. Work in this area has been called *Applied Natural Language Processing*, *Natural Language Engineering*, or more recently, *Language Technology*.

These aims go back as far as the earliest research and development in Natural Language Processing (NLP), which began with work on Machine Translation in the early 1950's. Early machine translation work pointed out serious problems in trying to deal with unrestricted, extended text in weakly circumscribed domains. This led NLP researchers in the 1960's and early 1970's to focus on question-answering dialogues in restricted domains such as baseball games in Green *et al.* (1961), airline schedules in Woods (1968), analyses of lunar rocks in Woods *et al.* (1972) and a "blocks world" in Winograd (1973). But as the development of meaning representations and reasoning needed for effective language processing became less and less language issues, the attention of NLP researchers shifted from developing Natural Language systems to solving individual language-related problems – e.g. developing faster, more efficient parsers; developing "weaker" and hence more realistic grammars whose complexity is only slightly more than context-free, cf. Joshi (1999); developing ways of handling referring expressions; modelling communicative goals and plans and their realization in language, etc. But now we have come full circle, and the recent explosion in information available over computer networks and recent demands for less frustrating automated telelphone-based service facilities made possible by advances in speech technology, have refocussed interest towards dealing with unrestricted extended text and dialogue.

With new attention being paid to discourse and dialogue, the aims of computational work in these areas can be seen to be similar to those of NLP in general:

- that of modelling particular phenomena in discourse and dialogue in terms of underlying computational processes;
- that of providing useful Natural Language services, whose success depends in part on handling aspects of discourse and dialogue.

By "phenomena" in discourse and dialogue, I mean either (1) a word, phrase and utterance whose interpretation is shaped by the discourse or dialogue context; and (2) a sequence of utterances whose interpretation is more than the sum of its component parts. What computation contributes is a coherent framework for modelling these phenomena in terms of *resource-limited inferential search* through a *space* of possible candidate *interpretations* (in language analysis) or candidate *realizations* (in language generation).

Inference here refers to any form of reasoning. The reasoning may be *non-defeasible*, according to logical principles that guarantee the correctness of its conclusions, as in correctly concluding from "John went to the zoo again", that John had gone to the zoo at least once before. Or the reasoning may be *defeasible*, producing plausible conclusions that are not necessarily correct, as in concluding from "John went to the zoo. He saw an owl", that John had seen the owl at the zoo.

Search refers to how one goes about determining discourse interpretation: there are often several *possible* ways to interpret a word, phrase, utterance or sequence of utterances in context, and one needs to find the intended, or at least the most likely, one. *Inferential search* refers to the roles that inference can play in this process: It can serve to (1) grow the search space in which the interpretation of an utterance will be found (or alternatively, the search space in which the surface realisation of some underlying conceptual form will be found), or (2) provide evidence relevant to evaluating candidate interpretations or surface realisations, or both. For example, in

(1) a. John arrived at an oasis. He saw the camels around the water hole and . . . .
b. John arrived at an oasis. He left the camels around the water hole and . . . .

inference can play one or both roles in interpreting the definite noun phrase "the camels". It can be used to link the camels to the oasis or to the means by which John got there. (This use of inference is sometimes called *bridging*.) And it can also be used in choosing which interpretation is more plausible – camels already at the oasis in (1a) since they are something John might observe and whose observation might be mentioned, and camels that John brought with him to the oasis in (1b) since they are something he could then leave.

Resource-limited refers to the fact that the computational processes used in discourse and dialogue do not have unlimited time or memory in which to carry out the search. *Resource-limited search* can manifest itself in terms of restrictions on the context from which search begins and/or as constraints on the way the search space can develop. For example, if there is a cost associated with inference, as in Hobbs *et al.* (1993) and Thomason and Hobbs (1997), that cost can be used to direct the growth of the search space towards low-cost solutions or to prune more expensive ones from it. (It can also be used to choose the lowest cost interpretation among those that can be completed, but that would not be a resource-limited process, as it would require first producing them all.)

This is not to imply that all computational work on discourse and dialogue involves resource-limited inferential search. Recent Language Technology work on discourse (mainly coreference identification) and dialogue (mainly call routing and other simple service interactions) exploits probabilistic methods based on frequencies gathered from large tagged corpora. I will say a bit more about this in Section 3.

Section 2 of this chapter provides a brief discussion of computational models of discourse and dialogue from the perspective of Computational Linguistics. Section 3 describes Language Technology in the area of discourse and dialogue, while Section 4 speculates on future directions and developments.

More extensive discussion of recent computational research and development can be found in the individual papers cited throughout this paper, in textbooks by Allen (1995) and by Jurafsky and Martin (2000), in a survey by Cohen (1996), and in the websites of the Association for Computational Linguistics' Special Interest Group on Discourse and Dialogue (SIGDial) (http://www.sigdial.org) and the Language Engineering Telematics project, MATE (http://mate.nis.sdu.dk/).

2 Discourse, Dialogue and Computation

2.1 Computational Models of Cognitive Processes in Discourse and Dialogue

Many aspects of language have their use and interpretation shaped by the discourse context:

- forms of reference, such as pronominal anaphora and deixis, and definite and deictic noun phrase (NP) reference;
- certain forms of ellipsis such as VP ellipsis, sluicing – e.g. "I know John goes swimming on New Year's Day but I don't know why", and background ellipsis – e.g. Q: "Will the shop open in June?" A: "No." Q: "In July?". (Other forms of ellipsis, such as gapping and conjunction reduction, are generally considered purely within the domain of syntax and do not appeal to the resources or processes associated with discourse.)
- the interpretation of clauses in terms of eventualities and their temporal, causal and rhetorical relations to one another;
- aspects of intonation and syntactic choice generally associated with *information structure* (i.e., notions of theme/rheme and background/focus).

What these phenomena share are *constraints* on their use, associated with a continually changing context that they contribute to, and reliance on *inference* to find and/or verify candidate intepretations. These features come from the resource-limited inferential search processes that underlie their generation and interpretation.

Consider, for example, pronominal reference. One of the earliest computational models of pronoun reference appears in LUNAR, cf. Woods (1978), which allowed geologists to pose English-language queries to a large database concerning the Apollo 11 lunar samples. LUNAR's treatment of pronominal anaphora in follow-up questions such as

(2) User: Do the breccias contain olivine?
LUNAR: . . .
User: Do they contain magnatite?

(3) User: What is the silicon content of each volcanic sample?
LUNAR: . . .
User: What is its magnesium concentration?

followed Karttunen (1976) in taking pronouns and definite NPs to refer to *entities* in a model of the discourse. In LUNAR, entities could be evoked through indefinite and definite NPs in a user's query, and referenced in the same or a subsequent query. Only the ten most recently evoked or referenced entities were considered possible referents for a subsequent pronoun or definite NP. Entities were tested for semantic fit in order of recency, with the first to fit taken to be the intended referent. This had the side effect of updating the referent's position in the *reference list*, removing it from its current position and inserting it at the start of the list, thereby delaying its dropping off the end. Recent theories of contextual reference based on an approach to contextual modelling called *Centering*, developed in the mid 1980's by Grosz *et al.* (1995), have similar features.

Centering follows work by Sidner (1982) in imposing a finer structure on context than LUNAR, by assigning to each utterance in a discourse, both a unique *backward-looking center* C_b and a rank-ordered list of *forward-looking centers* C_f. The C_f-list for one utterance comprises the possible candidate referents for pronouns in the next utterance. One question is how to structure this search, and different ordering metrics have been proposed for different languages (for Italian in Di Eugenio (1997), for Turkish in Turan (1995), and for Japanese in Iida (1997). Another question is how to use the C_b in identifying a preferred solution. For example, Brennan *et al.* (1987) introduced the idea of *center transition preferences* that prefer interpreting a pronoun in a way that retains the same C_b between utterances, or barring that, only changes it in particular ways. The C_b and C_f-list are then updated at the end of each utterance.

Brennan, Friedman and Pollard's treatment is not incremental. In contrast, Strube (1998) proposed a simpler form of centering that returns to models such as LUNAR in (1) abandoning the backward-looking center C_b and center transitions and (2) using only a finite ordered list of salient candidates. This allows updating to take place as soon as a referring expression is processed, with an entity's insertion into the list determined by how the speaker has chosen to specify it with respect to the "familiarity scale" given in Prince (1981). In this scale, Prince distinguishes between entities presented as *new* to the discourse, entities presented as already *evoked* by the discourse or the outside situation, and entities presented as *inferrable* from something already introduced into the discourse. A feature of this scale is that well-known individuals, when first introduced into a discourse, are nevertheless considered *new* (in Prince's terms, *unused*). In Strube's incremental approach, if an entity is already on the list, its position on the list may change on subsequent reference, reflecting how it has been specified. Besides being simpler, Strube's algorithm better reflects intended interpretations than other centering algorithms, although it still does not provide a complete account of pronominal reference.

It should be noted that centering and earlier focus models have also been used to guide decisions about the use of pronouns in generating text in work by McKeown (1985) and by Dale (1992), though the decision process is not simply the reverse of that used in interpretation. More recently, McCoy and Strube (1999) have considered whether considering changes in temporal focus could explain a speaker's decision to use a name or definite NP where centering allows the use of a pronoun: it is a better model, but still incomplete.

Computational models of other discourse phenomena – including other forms of contextual reference – highlight other features of the resource-limited inferential search that can be seen to underpin their processing:

- **Definite NPs** – The intended referent of a definite NP need not have been explicitly mentioned in the prior discourse, as long as it can be inferred from what has been. For example, in

  (4) Phone "Information". *The operator* should be able to help you.

  the definite NP, *the operator* refers to the telephone operator you reach when phoning information. The referent of a definite NP can but need not be a member of the set of initial candidates that a reference resolution process begins with. Computational research attempts to specify not just what these additional candidates may be, but the specific search processes by which they will be found and the intended referent correctly identified as in Bos *et al.* (1995); Hahn *et al.* (1996); Hobbs *et al.* (1993); Markert and Hahn (1997). From the perspective of text generation, choosing whether to use a definite NP (and, if so, choosing one sufficient to refer uniquely to the intended referent) involves both search and inference for other entities in the context that block referential uniqueness and search for properties that distinguish the intended referent from the remaining others, as in Dale and Haddock (1991); Dale and Reiter (1995); Horacek (1997); Stone and Doran (1997); Stone and Webber (1998).

- **Demonstrative Pronouns** – These expressions highlight the need for an augmented candidate set for reference – not only the individuals and/or sets evoked by individual NPs (or sets of NPs) but also properties and eventualities evoked by predicates, clauses and larger units of discourse (*discourse segments*). For example,

  (5) Phone "Information". *That* should get you the information you need.

  As discussed in Webber (1988, 1991) and later in Asher (1993) and Stone (1994), resolution of demonstrative pronouns appears, in part, parasitic on an update process for discourse segments to provide possible referents. Where demonstratives refer to individuals, Davies and Isard (1972) have pointed out the role of stress in preferring one candidate over another in resolving a demonstrative pronoun versus an anaphoric pronoun

  (6) Think of a number, square it, and then multiply [*it*, *that*] by three.

  In NL generation, I am not aware of any more recent attempt to articulate the processes involved in generating demonstrative pronouns than the work of Davey (1974), generating explanations of what happened in a game of tic-tac-toe.

- **Clausal Relations** – It has long been noted that a discourse composed of a sequence of clauses requires recognizing intended relations between them (often called *coherence relations*), although Scott and de Souza (1990) and others have pointed out that similar relations hold between phrases and between phrases and clauses as well. Such relations have been taken to contribute to the underlying substructures and their interpretation as explanations, descriptions, proposals, corrections, etc. For example, one must recognize the different relations between the clauses in (a) and in (b), in order to understand them correctly:

  (7) a. Phone "Information". The operator will have the number you want.
  b. Phone "Information". It won't cost you anything.

  Rhetorical Structure Theory, as presented in Mann and Thompson (1988), posits a fixed set of relations with constraints on their applicability, but not how they would be used in any kind of process involved in understanding or generation. Identifying clausal relations appears resource-limited in two ways: in establishing what the current clause is related to – the previous clause or some larger segment in which it is embedded – and in establishing what relation(s) hold between them. With respect to the former, while a speaker may be describing more than one event or situation at a time or connecting up many strands into an explanation, the listener, nonetheless, appears limited in terms of how many things s/he can be attending to or keeping in mind simultaneously and on how s/he can use evidence in deciding how a new clause fits in. Computational work here has focussed on the updating process, including the role of tense and aspect as evidence for what should be updated and how. Relevant work here includes that of Hitzeman *et al.* (1995), Kameyama *et al.* (1993), Kehler (1994), Moens and Steedman (1988), and Webber (1988). Different inferential processes that could be used in recognizing the intended relations between clauses within a discourse are described in Hobbs *et al.* (1993), Lascarides and Asher (1993), and Thomason and Hobbs (1997). Discussion of bases for relating clauses in discourse can be found in Grosz and Sidner (1986), Moore and Pollack (1992), Moser and Moore (1996) and Webber *et al.* (1999b,c).

- **Information Structure** – Information structure deals with: (1) what a speaker conveys as being the topic under current discussion and consequently, his or her contribution towards that topic (*theme* vs. *rheme*), and (2) what a speaker takes to be in contrast with things a hearer is or can be attending to (*focus* vs. *background*), cf. Halliday (1967b, 1970) and Steedman (2000). Information structure manifests itself in both sentential syntax and intonation.

  Just as interpreting a clause as an eventuality requires identifying its temporal, causal and/or rhetorical relations with others in the discourse, the process involved in recognizing the *theme* of an utterance also requires recognizing its relation to the theme of the previous utterance or, more generally, to context. This again requires an inferential search process. So too do elements marked intonationally or syntactically as being in contrast, require searching through a limited set of elements that could serve as a source of contrast and inferring the intended alternative set to which both source and contrast item belong. This again is a resource-limited inferential search process. Less work has, to date, been done on characterizing and modelling these processes, but cf. Hajicova *et al.* (1995); Prevost (1995); Prevost and Steedman (1994); Steedman (1996a). Interest in the area is growing due to its use in improving intonation in Spoken Language Generation.

- **Repetition and Restatement** – Speakers have been observed to often re-state information already introduced into a dialogue. This would contradict the Maxim of Quantity in Grice (1975), unless, as suggested in Walker (1996a,b), there are resource-limitations on the propositions a listener can be attending to and all propositions needed to draw an inference must be attended to simultaneously. In Walker's model, recently introduced or mentioned propositions are held in an unordered cache (rather than an ordered list), and various cache management strategies are explored to see which correspond more closely to observed human behaviors.

There are other discourse phenomena whose interpretation depends on context - from the contextual presuppositions of individual words such as "also" and "other", cf. Bierner and Webber (1999), to the contextual presuppositions of clauses headed by "when" and "since". Eventually, all such phenomena should be brought within the purview of a computational account framed in terms of resource-limited inferential search.

2.2 Computational Models of Rational Agency

Discourse and dialogue pragmatics (including speech acts, relevance, Gricean maxims, etc.) in the procedural view taken here, emerge from considerations of speaker and hearer as rational agents. Rational agency views discourse and dialogue as behavior arising from and able to express an agent's beliefs, desires and intentions (i.e., what the agent is committed to achieving), constrained by its resource limitations, as described in Bratman (1987); Bratman *et al.* (1988). Both *planning* – the process that maps an agent's intentions into actions – primarily communicative, in the case of speakers as agents – and *plan recognition* – the process by which a hearer recognizes what the speaker is trying to accomplish – are resource-limited inferential search processes. However, they are shaped by two factors beyond those discussed in the previous section:

- The context in which they operate *changes continually* in consequence of actions.
- The changing context will only ever be *partially known*.

The former means that any look-ahead or pre-computations they do must reflect the fact that beliefs and intentions of speaker and hearer can evolve or even change precipitously during the course of a discourse or dialogue. The latter means that these processes must be able to elicit essential information; to provide useful output on the basis of assumptions as well as facts; and to modify or efficiently recompute new output if and when these such assumptions are found inconsistent or wrong.

The basic framework for this work comes from the "goal (intention) begets plan" approach to planning developed and used in Artificial Intelligence since the late 1960's, following ideas in Newell and Simon (1963). The most widely known version is called the STRIPS algorithm, described in Fikes and Nilsson (1971). The data structures used by this algorithm capture such elements of intention and action (including communicative action) as the fact that actions have preconditions that must hold for them to have their intended effects and that may therefore be themselves adopted as goals realizable through further communicative actions; and that actions may have several different effects on the world. Later versions incorporated additional features such as a view of actions at different levels of aggregation and abstraction, in work by Di Eugenio (1998); Di Eugenio and Webber (1996) and by Moore (1995); actions that can be done to acquire information, which can then affect the further plan or trigger further planning; and the fact that changing an agent's beliefs can cause him or her to adopt particular goals, etc., in the work of Allen (1995), Appelt (1985), Cohen and Perrault (1979) and Litman and Allen (1990). This is all well-described in Allen (1995).

More recently, researchers have begun to develop more complex computational models of language as rational planned action, reflecting, *inter alia*:

- that the beliefs of the planner/speaker might differ from those of the hearer and even be incorrect. Pollack (1986) shows how, for a speaker's communicative actions and underlying plan to be understood with respect to their beliefs, the hearer must be able to infer or elicit what beliefs support the speaker's inferred plan as well as inferring that plan itself.

- that dialogue can be used to explore and negotiate possible courses of action, not just accomplish action, shown in the work of Di Eugenio *et al.* (1998) and Lambert and Carberry (1992, 1999).

- that dialogue involves a collaboration among all its participants. Thus, Grosz and Kraus (1996); Grosz and Sidner (1990), Lochbaum (1998) and McRoy and Hirst (1995) all show that the planning process for achieving goals through dialogue is more complex than when only a single planning agent is involved.

- that planning agents have *preferences* shaping the way they choose to realize goals as plans of action. Thus, both Chu-Carroll (1997) and Elzer *et al.* (1999) show that in an advisory dialogue, the participant in the advisory role must be able to infer or elicit those preferences, as well as the advisee's possibly incorrect beliefs.

- that communicative actions – e.g., to justify one course of action over another, to explain how a process works, etc. – may not succeed in their goal, requiring the speaker to use the hearer's feedback to produce a new or augmented plan whose communicative actions will accomplish the goal or support the initial communication in doing so (e.g., through clarification or explanation), as in the work of Moore (1995) and Young *et al.* (1994);

- that a communicative action conveys information to achieve particular intentions – cf. Grosz and Sidner (1986), Moore and Paris (1993) and Moore and Pollack (1992); that there is a potentially many-to-many relation between information and intention – cf. Di Eugenio and Webber (1996),Moore and Pollack (1992), Pollack (1991) and Stone and Webber (1998); and that information and intention must be combined in generating communicative actions and extracted in understanding them. How to do this harkens back to discussions of the *modularity* of syntax and semantics in Fodor (1983). That is, Moore and Pollack (1992) argue that the recognition of informational relations cannot be ordered *a priori* before the recognition of intentional relations, and vice versa. But whether, in human language processing, the processes operate non-deterministically in parallel on distinct data structures as in Hobbs (1996) or are integrated into a single process operating on a single integrated database, as in Moore (1995), or something in between, as in Thomason and Hobbs (1997), is not clear. Nor is the optimal form of integration yet known from a purely computational engineering perspective

The brief discussions in the next two sections will show an ever-increasing number of applications in the areas of discourse and dialogue. As in the past, this will also likely act as a spur to increased theoretical understanding of discourse and dialogue in terms of cognition and rational agency.

3 Discourse, Dialogue and Language Technology

As noted in Section 1, computational work on discourse and dialogue has been driven equally by the desire to understand these phenomena as manifestations of intrinsically computational processes and by the desire to satisfy existing or potential consumer needs. In the early days of NLP, those needs were taken to be machine translation (MT) and database question/answering. The latter drove much of the early research on discourse and dialogue (cf. Section 2.1 and work on "cooperative question answering" such as Cheikes and Webber (1988), Joshi (1982); Joshi *et al.* (1987), Pollack (1986) and Webber (1986)). But despite early attempts to provide NL "front ends" to database systems to handle user queries, and NL "back ends" to produce cooperative responses, the consumer base of casual users of database systems, for whom such "wrappers" were designed, never really materialized.

Recently however, there has been renewed interest in cooperative dialogues, made possible by improvements in automated speech recognition and spurred by corporate desires for automated (spoken) telephone and web-based service interactions, cf. Litman *et al.* (1998) and Walker *et al.* (1998). Similarly, for most of its history, MT ignored discourse and dialogue as a relevant factor in translation, but again, speech recognition has made a difference: now the effort to provide "translating telephones" requires making use of whatever sources of knowledge can be brought to bear. Finally, the recent explosion of freely available electronic text and services on the World Wide Web (WWW) has become a potent driver of Language Technology, including work on discourse and dialogue.

By and large, Language Technology methods aim towards broad-coverage at low cost. They eschew underanding, tolerating what may, from a theoretical perspective, appear to be a high rate of errors, as long as they individually or together lead to significant improvements in overall task performance. In web-based information retrieval, such improvements may involve either increasing *precision* (i.e., reducing the large number of "false positives" in any search that tries to avoid missing too many "true positives"), or increasing *recall* (i.e., increasing the number of "true positives" that might otherwise be missed when anaphora and ellipses replace more lexically "revealing" evidence). The former is being addressed indirectly, by trying to identify what *parts* of a text might potentially be relevant (sub-topic identification) and by trying to identify the sentences in a (short) document that best reveal its content and outputting those sentences as a *summary* of the text, as in Kupiac *et al.* (1995) and Mani and Maybury (1998), thereby enabling people to make relevance judgements faster, based on a smaller portion of the text, as in the work of Hearst (1994) and Reynar (1998). Where those sentences themselves contain context-dependent discourse phenomena, efforts are made to include sufficient previous text that people can resolve them. The latter is being tackled by superficial methods of coreference resolution that may guess incorrectly in places or only attempt the easy cases – cf. Baldwin (1997), Kameyama (1997), Kennedy and Boguraev (1996).

Work is also being done on developing and using *dialogue models* to support more effective telephone- and web-based computer services, including call-routing – cf. Chu-Carroll and Carpenter (1999), emergency planning-support systems – cf. Allen *et al.* (1996) and Heeman *et al.* (1998), and travel information – cf. Bennacef *et al.* (1996), Carlson and Hunnicut (1996), Flycht-Eriksson and Jonsson (1998) and Seneff *et al.* (1998). A dialogue model is an efficient description of standard patterns of action in a dialogue, often encoded as a finite-state or probabilistic automaton to reflect the role of the current state in predicting (or constraining) the next one. The development of a dialogue model thus requires two things:

- a classification scheme for dialogue actions that (1) can be annotated reliably, cf. Carletta *et al.* (1997), on the basis of superficial evidence, and (2) can support effective predictions. Dialogue acts are commonly classified functionally, at some abstract level level connected with the type of task being performed (e.g., *greet*, *suggest*, *reject*, etc. as in Samuel *et al.* (1998) (meeting planning dialogues); *restate plan*, *elaborate plan*, etc. as in Heeman *et al.* (1998) (complex task-planning dialogues), also cf. Poesio and Traum (1997); Reithinger and Klesen (1997); Traum and Hinkelman (1992). But they can also be usefully classified by the topic they address, as in Chu-Carroll and Carpenter (1999) and Jokinen *et al.* (1998).

- a reliable method of correlating evidence from dialogue actions and their context with the classification of dialogue actions, so that the dialogue model can be used in speech recognition, dialogue understanding, and/or response generation. The usual problem is that one does not know which combination of which surface features – including particular vocalizations, particular words and/or phrases, particular surface-syntactic features, the class of the previous utterance(s), etc. – provide reliable evidence, including potentially different features and a different combination for each class in the scheme. So data must first be reliably annotated for features that could serve as evidence. After that, a machine-learning method such as decision-tree induction, transformation-based learning, cf. Samuel *et al.* (1998), or neural network learning can be used to build the classification scheme. For clarity, one may use sets of probabilistic automata, each trained to a different kind of evidence, combined using the standard calculus of probabilities, as in the dialogue managers developed by Stolcke *et al.* (March 1998) and Taylor *et al.* (1998).

A dialogue model can also be designed to make use of a *dialogue strategy*, embodying decisions for how to respond to dialogue actions on the part of the human user that admit a variety of system responses. Here, both machine learning and purely statistical techniques are being used to identify effective strategies and evaluate their effectiveness, cf. Litman *et al.* (1998) and Walker *et al.* (1998).

4 Speculations on Future Directions and Developments

Before closing this chapter, I would like to add my speculations on where useful future developments are likely to occur in computational work on discourse and dialogue.

- The development of a single integrated account of context management (updating, evolution and retrieval) will provide better understanding of the whole range of resource-bounded, contextlinked discourse phenomena, including contextual reference, information structure, and clausal relations.

- The development of an integrated account of both informational and intentional aspects of discourse and dialogue will initially support more principled and effective text and speech generation systems and eventually, understanding systems as well.

- The emergence of new tasks related to discourse and dialogue will turn researchers' attention to additional communicative phenomena. For example, broadening communication channels to support "face-to-screen" or even "face-to-face" spoken interaction with computer systems will focus attention on information to be gained from a speaker's gestures and their use in enriching the speaker's message or in disambiguating it, as in the work of André *et al.* (1998), Cassell *et al.* (1994); Cassell and Stone (1999), Koons *et al.* (1993) and McGee *et al.* (1998).

- Improvements in the handling of current phenomena, such as clausal reference and clausal relations, will be needed to support more difficult future tasks involving "mapping" natural language texts to formal specifications (e.g., for software, to support system construction and verification) or to terminologies (e.g., in medicine, to support knowledge discovery and refinement of practice standards).

- Just as at the sentence-level, lexical semantics poses more difficult representational and reasoning problems than Montague-style formal semantics, at the discourse-level, the semantics of events and actions poses as yet unsolved problems in representation and reasoning. The emergence of solutions to these problems should lead to improved performance on information retrieval and text summarization tasks, and may also support vision systems to use Natural Language discourse and dialogue to talk about what they they see as they act in the world.

- Just as sentence-level processing has sought lexically-based syntactic/semantic formalisms that can facilitate both understanding and generation (cf. Tree-Adjoining Grammar, described in Joshi (1987); Combinatory Categorial Grammar, described in Steedman (1996b, 2000), etc.), similar efforts by Danlos (1997) and by Webber *et al.* (1999a,b,c) will contribute to facilitating both discourse understanding and generation.

- As in grammar modelling, where the utterances that people produce are influenced by a wide range of structural and performance factors and where probabilistic models may provide the most reliable predictions, probabilistic models used in discourse and dialogue will improve as they move to incorporate more and more sophisticated models of the phenomena they aim to approximate.

- More and more on-line documents are being prepared using mark-up languages like SGML or document-type declarations specified in XML. Mark-up reflecting function (e.g., heading, citation, pie_chart, etc.) rather than appearance (e.g., italics, flushright, etc.) will likely facilitate more effective information retrieval and other Language Technology services such as summarization and multi-document integration.

There seems no doubt that computational approaches are contributing their share to our understanding of discourse and dialogue and to our ability to make use of discourse and dialogue in building useful, user-oriented systems.

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