

Centering in Naturally-Occurring Discourse: An Overview

Marilyn A. Walker
ATT Laboratories
2D-441, 600 Mountain Ave.
Murray Hill, N.J. 07974
walker@research.att.com

Aravind K. Joshi
Computer and Information Science
University of Pennsylvania
Philadelphia, PA
joshi@linc.cis.upenn.edu

Ellen F. Prince
Linguistics
University of Pennsylvania
Philadelphia, PA
ellen@central.cis.upenn.edu

1 Introduction

Centering is a model of the conversants' center of attention in discourse that is concerned with the relationship of attentional state, inferential complexity and the form of referring expressions. Centering models discourse processing factors that explain the difference in the perceived coherence of discourses such as (1) and (2) from (Hudson-D'Zmura, 1988):

- (1) a. Jeff helped Dick wash the car.
b. He washed the windows as Dick waxed the car.
c. He soaped a pane.
- (2) a. Jeff helped Dick wash the car.
b. He washed the windows as Dick waxed the car.
c. He buffed the hood.

The prediction of purely semantic or inferential theories of discourse understanding (cf. (Hobbs, 1985)) is that there should be no difference in coherence between (1) and (2). According to these theories, the agent in (1c), realized by the pronoun *he*, can only cospecify the discourse entity realized by *Jeff* because the verb *soaping* can only be related to the washing event, while the agent in 2c can only cospecify the discourse entity realized by *Dick* because the verb *buffing* can only be related to the waxing event.

Centering predicts that (2) is harder to process than (1). The central idea is that both discourses present the discourse entity that is realized by *Jeff* as the CENTER of the discourse in utterances a and b, but in (2), utterance (2c) shifts the CENTER of the discourse to the entity realized by *Dick*. The combination of the shift in center and the use of a pronominal form to realize the new center are factors that contribute to

making (2) less coherent than (1).

Centering is a synthesis of two strands of earlier work: (1) research by Joshi, Kuhn and Weinstein (Joshi and Kuhn, 1979; Joshi and Weinstein, 1981); and (2) research by Grosz and Sidner (Grosz, 1977; Sidner, 1979; Grosz and Sidner, 1986). Joshi, Kuhn and Weinstein proposed centering as a model of the complexity of the inferences required to integrate the meaning of an utterance into the meaning of the preceding discourse. Centering was proposed as a constraint on quantification; in a centered logic, universal instantiation is allowed only if the universally quantified NP is a center and existential generalization is allowed only over a centered entity. Furthermore, on this view of centering, the underlying logic for utterance processing is an ‘almost monadic’ predicate calculus. The motivation for this approach is that inferencing is much easier in monadic predicate calculus (MPC); validity in MPC is decidable whereas validity in the full predicate calculus is undecidable. Grosz and Sidner proposed that attentional state in discourse consisted of two levels of focusing: global and local (Grosz, 1977; Sidner, 1979). The centering proposals in (Grosz, Joshi, and Weinstein, 1983; Grosz, Joshi, and Weinstein, 1986; Grosz, Joshi, and Weinstein, 1995) defined centering as a model of some aspects of local focus (Sidner, 1979). The chapters by Grosz and Sidner (this volume) and Joshi and Weinstein (this volume) provide additional motivation and background on these bases for centering theory, and suggest key areas for future work.

In order to help the reader to understand the significance of the various contributions in the volume and relate them to the open issues in centering, this chapter first summarizes the concepts central to centering theory in Section 2. The summary is based on the original centering proposals in (Grosz, Joshi, and Weinstein, 1986), henceforth GJW86, and (Grosz, Joshi, and Weinstein, 1995), henceforth GJW95, and on the formulation of these proposals and the centering algorithm specified in (Brennan, Friedman, and Pollard, 1987), henceforth BFP. These original proposals left a number of issues open, many of which could only be tested empirically. Section 3 groups the open issues into five general themes: (1) utterance level issues in centering; (2) centering as a crosslinguistic universal; (3) information structure and centering; (4) the role of centering in processing models of discourse; and (5) discourse structure and centering. The chapters in the book provide detailed studies and empirical evidence addressing these themes. Section 3 discusses each theme and outlines how each chapter addresses the open issues.

2 Centering Theory

The centering model is very simple. Discourses consists of constituent segments and each segment is represented as part of a discourse model. Centers are semantic entities that are part of the discourse model for each utterance in a discourse segment. The set of FORWARD-LOOKING CENTERS, $Cf(U_i, D)$, represents discourse

entities evoked by an utterance U_i in a discourse segment D (Webber, 1978; Prince, 1981). The BACKWARD-LOOKING CENTER, $Cb(U_i, D)$ is a special member of the Cf , which represents the discourse entity that the utterance U_i most centrally concerns, similar to what is elsewhere called the ‘topic’ (Reinhart, 1981; Horn, 1986). The Cb entity links the current utterance to the previous discourse.

The set of FORWARD-LOOKING CENTERS, Cf , is ranked according to discourse salience. This ranking is a partial order. The highest ranked member of the set of forward looking centers is referred to as the PREFERRED CENTER, Cp .¹ The PREFERRED CENTER represents a prediction about the Cb of the following utterance. Sometimes the Cp will be what the previous utterance of discourse was about, the Cb , but this is not necessarily the case. This distinction between looking back to the previous discourse with the Cb and projecting preferences for interpretation in subsequent discourse with the Cp is a key aspect of centering theory.

In addition to the structures for centers, Cb and Cf , centering includes a set of rules and constraints.

- **CONSTRAINTS**

For each utterance U_i in a discourse segment D consisting of utterances U_1, \dots, U_m :

1. There is precisely one backward looking center $Cb(U_i, D)$.²
2. Every element of the forward centers list, $Cf(U_i, D)$, must be realized in U_i .
3. The center, $Cb(U_i, D)$, is the highest-ranked element of $Cf(U_{i-1}, D)$ that is realized in U_i .

Constraint (1) says that there is one central discourse entity that the utterance is about, and that is the Cb . Psycholinguistic evidence supports the claim that there is not more than one Cb (Hudson-D’Zmura, 1988; Gordon, Grosz, and Gilliom, 1993).

The second constraint depends on the definition of *realizes*. GJW95 simply state that the precise definition of U REALIZES a center c depends on the semantic theory that one adopts. GJW86 defined the realize relation drawing on situation theory (Barwise, 1988): An utterance U *realizes* a center c if c is an element of the situation described by U , or c is the semantic interpretation of some subpart of U . By this definition, the relation REALIZE describes pronouns, zero pronouns, explicitly realized discourse entities, and those implicitly realized centers that are

¹The term PREFERRED CENTER was introduced by (Brennan, Friedman, and Pollard, 1987); the Cp roughly corresponds to Sidner’s EXPECTED FOCUS (Sidner, 1983).

²Because GJW86 and GJW95 do not discuss center instantiation, empirical and applied work on centering has treated this constraint as stating that there is **not more than one** Cb , thus allowing the possibility that an utterance has no Cb (cf. BFP). See (Kameyama, 1985; Walker, Iida, and Cote, 1994) for a discussion of center instantiation.

entities inferable from the discourse situation (Prince, 1978; Clark and Marshall, 1981; Prince, 1981).³

A specialization of the relation REALIZE is the relation DIRECTLY REALIZE. A center is directly realized by an utterance if it is the semantic interpretation of a phrase in the utterance.

Constraint (3) stipulates that the ranking of the forward centers, Cf, determines from among the elements that are realized in the next utterance which of them will be the Cb for that utterance. Thus, the Cf ranking plays a critical role in the model. If the PREFERRED CENTER, Cp(U_i), is realized in U_{i+1} , it is predicted to be the Cb(U_{i+1}). The Cf ranking is determined by a number of factors, such as the grammatical role in which the entity is realized, surface order of realization, and information status. Below we use rankings proposed in previous work to illustrate our examples; the issue of which factors are most relevant for ranking in different languages is discussed in more detail in section 3.

Centering also includes two rules:

- **RULES**

For each U_i in a discourse segment D consisting of utterances U_1, \dots, U_m :

1. If some element of $Cf(U_{i-1}, D)$ is realized as a pronoun in U_i , then so is $Cb(U_i, D)$.
2. Transition states are ordered. The CONTINUE transition is preferred to the RETAIN transition, which is preferred to the SMOOTH-SHIFT transition, which is preferred to the ROUGH-SHIFT transition.

Rule (1) is sometimes called the Pronoun Rule. It captures the intuition that pronominalization is one way to indicate discourse salience, and that backward-looking centers, Cbs, are often deleted or pronominalized. It follows from Rule (1) that, if there are multiple pronouns in an utterance, realizing discourse entities from the previous utterance, then one of these pronouns must realize the Cb. In addition, if there is only one pronoun, then that pronoun must be the Cb. Kameyama originally proposed that zero pronouns in Japanese correspond to unaccented pronouns in English (Kameyama, 1985; Kameyama, 1988), and Rule (1) was extended directly to zero pronouns in (Walker, Iida, and Cote, 1990; Prince, 1994; Walker, Iida, and Cote, 1994; Turan, 1995; Di Eugenio, 1990) *inter alia*.

Rule (2) provides a typology of transitions that can be used to measure the coherence of the discourse segment in which the utterance occurs. Measuring coherence is based on an estimate of the hearer's inference load, **relative to** other choices the speaker had as to how to realize the same propositional content. Rule (2) claims that some transitions between utterances are more coherent than others by stipulating

³Birner (this volume), Hurewitz (this volume), Gundel (this volume), and (Strube, 1996) discuss the role in centering of entities inferable from the discourse situation.

	$Cb(U_i) = Cb(U_{i-1})$ OR $Cb(U_{i-1}) = [?]$	$Cb(U_i) \neq Cb(U_{i-1})$
$Cb(U_i) = Cp(U_i)$	CONTINUE	SMOOTH-SHIFT
$Cb(U_i) \neq Cp(U_i)$	RETAIN	ROUGH-SHIFT

Figure 1: Centering Transition States, Rule 2

that those transitions are preferred over others. For example, discourses that continue centering the same entity are more coherent than those that repeatedly shift from one center to another. There is some empirical evidence for Rule 2's preference ranking, which will be discussed below, however a number of open issues remain. Section 3 discusses whether Rule 2 applies on an utterance-by-utterance basis or over longer stretches of discourse, and whether the preference ranking should be modified.

The typology of transitions from one utterance, U_{i-1} , to the next utterance, U_i , is based on two factors: whether the backward-looking center, Cb , is the same from U_{i-1} to U_i , and whether this discourse entity is the same as the preferred center, Cp , of U_i .⁴

1. $Cb(U_i) = Cb(U_{i-1})$, or $Cb(U_{i-1}) = [?]$
2. $Cb(U_i) = Cp(U_i)$

The definition of transition states from BFP is summarized in Figure 1. We use the notation $Cb(U_{i-1}) = [?]$ for cases where there is no $Cb(U_{i-1})$.

If both (1) and (2) hold, then the two utterances are related by a CONTINUE transition, which corresponds to cases where the speaker has been talking about a particular entity and apparently intends to continue talking about that entity.

If (1) holds but (2) doesn't hold, then the two utterances are related by a RETAIN transition. GJW86 propose that RETAIN corresponds to a situation where the speaker is intending to SHIFT onto a new entity in the next utterance and is signaling this by realizing the current center in a lower ranked position on the Cf.

If (1) doesn't hold, then the two utterances are related by one of the SHIFT states depending on whether or not (2) holds. If $Cb(U_i) = Cp(U_i)$ then the two utterances

⁴This restriction of the relation between the $Cb(U_i)$ and the $Cb(U_{i-1})$ to identity probably misses important generalizations about entities related to the current Cb by functional dependency or poset relations. Joshi and Weinstein proposed that functionally dependent entities could continue the current Cb , and both Birner (this volume) and Hurewitz (this volume) explore how chains of anaphoric dependencies based on these relations should be handled within centering theory.

are related by a SMOOTH-SHIFT transition, but if $Cb(U_i) \neq Cp(U_i)$ then the two utterances are related by a ROUGH-SHIFT transition. The distinction between SMOOTH and ROUGH SHIFT was first made by BFP, and some work in centering doesn't distinguish these two types of shifts. However, the distinction is supported by empirical work that shows that ROUGH-SHIFT transitions are nonexistent or extremely rare in naturally occurring discourse (Di Eugenio, this volume), (Hurewitz, this volume).

The combination of the constraints, rules and transition states makes a set of testable predictions about which interpretations hearers will prefer because they require less processing. For example, maximally coherent segments are those that require less processing time. A sequence of a CONTINUE followed by another CONTINUE should require the hearer to keep track of only one main discourse entity, which is currently both the Cb and the Cp. A single pronoun in an utterance is the current Cb (by Rule 1) and can be interpreted to cospecify the discourse entity realized by $Cp(U_{i-1})$ in one step (Constraint 3).

Below, we show how the centering rules and constraints apply to the discourses in 1 and 2, repeated here for convenience, and annotated with centering data structures and transitions.

(1) a. Jeff helped Dick wash the car.

Cb:	[?]
Cf:	[JEFF, DICK, CAR]
Centering Transition:	No CB

b. He washed the windows as Dick waxed the car.

Cb:	[JEFF]
Cf:	[JEFF, WINDOWS DICK, CAR]
Centering Transition:	CONTINUE

c. He soaped a pane.

Cb:	[JEFF]
Cf:	[JEFF, PANE]
Centering Transition:	CONTINUE

(2) a. Jeff helped Dick wash the car.

Cb:	[?]
Cf:	[JEFF, DICK CAR]
Centering Transition:	No CB

b. He washed the windows as Dick waxed the car.

Cb:	[JEFF]
Cf:	[JEFF, WINDOWS, DICK, CAR]
Centering Transition:	CONTINUE

c. He buffed the hood.

Cb:	[DICK]
Cf:	[DICK, HOOD]
Centering Transition:	SMOOTH-SHIFT

Remember that the members of the Cf are discourse entities, represented by small caps in the examples. In (1) and (2), the ranking of the Cf is based on BFP's Cf ranking in (3).

(3) **Cf Ranking by Grammatical Function:**

Subject > Object(s) > Other

This Cf ordering ranks discourse entities realized in SUBJECT positions more highly than entities realized in OBJECT position, which are both then ranked more highly than entities realized in subordinate clauses or as other grammatical functions.

Utterance 2b is a CONTINUE transition because the Cb is the same as in 2a and because the Cp(2b) is the same as the Cb(2b). In contrast, 3c is a SMOOTH-SHIFT transition, because the Cb has changed from 3b, but the Cp(3b) is the same as the Cb(3b).

According to the centering model, (2) is less coherent than (1). Since (2b) is a CONTINUE with the discourse entity realized by *Jeff* as the Cb, the speaker has indicated an intention to CONTINUE talking about the discourse entity realized by *Jeff*. However, despite the indicated intent, in (2c) the speaker SMOOTH-SHIFTS to talking about the discourse entity realized by *Dick*. The predicted preference for a CONTINUE over the other transitions means that the speaker misleads the hearer; the hearer first interprets the pronoun *he* in 3c as the Cp(U_{i-1}) and then has to revise this interpretation. Hudson-D'Zmura and Tanenhaus (this volume) show that this corresponds to both an increase in processing time, and an increase in subjects' judgments that the discourse in (2) doesn't make sense.

In (2) and (3), centering has no effect on the interpretation of the anaphors in the dialogue. To see the effect of the preference for CONTINUE over RETAIN on the interpretation of zero pronouns in Japanese, consider the Japanese discourse in 4 from (Walker, Iida, and Cote, 1994). Zero pronouns are indicated by 0 in the Japanese utterances and the names in parentheses in the translations in 4b and 4c indicate discourse entities realized by zero pronouns. There are two possible interpretations of the zero pronouns in (4c), shown as Cf1 and Cf2:

(4) a. Taroo wa saisin no konpyuutaa o kaimasita.

TOP/SUBJ newest of computer OBJ bought

Taroo bought a new computer.

Cb:	TAROO
Cf:	[TAROO, COMPUTER]

b. 0 John ni sassoku sore o misemasita.

TOP/SUBJ John OBJ2 at once that OBJ showed

(Taroo) showed it at once to John.

Cb:	TAROO	
Cf:	[TAROO, JOHN, COMPUTER]	CONTINUE

- c. 0 0 atarasiku sonawatta kinoo o setumeisimasita.
 SUBJ OBJ2 newly equipped function OBJ explained
 (He) explained the newly equipped functions to (him).

Cb:	TAROO
Cf1:	[TAROO, JOHN] CONTINUE TOP/SUBJ OBJ

(Taroo) explained the newly equipped functions to (John).

Cb:	TAROO
Cf2:	[JOHN, TAROO] RETAIN TOP/SUBJ OBJ

(John) explained the newly equipped functions to (Taroo).

In 4, the centering data structures are based on the Cf ranking for Japanese from (Walker, Iida, and Cote, 1994):

(5) **Cf Ranking for Japanese:**

(GRAMMATICAL OR ZERO) TOPIC > EMPATHY > SUBJECT > OBJECT(S) > OTHERS

According to this Cf Ranking, discourse entities realized in TOPIC are ranked more highly than entities which the speaker marks as the EMPATHY LOCUS.⁵ Entities realized in the EMPATHY LOCUS are ranked more highly than entities realized as SUBJECT, and SUBJECT entities are ranked more highly than entities realized in OBJECT position, which are ranked more highly than entities realized in subordinate clauses or as other grammatical functions. In Japanese, each of these functions has a corresponding marker: for example *wa* marks TOPIC and *o* marks OBJECT. As the centering data structures for 4c show, there are two possible interpretations for 4c. How do we use the centering rules and constraints to make predictions as to which interpretation the hearer will prefer?

The main verb of utterance 4(c), *explained*, requires an animate subject and indirect object. Since there are two animate zeros in 4c, both Ziroo and Taroo must be realized in 4c.⁶ Constraint (3) restricts the Cb to Taroo as the highest ranked element from the Cf(4b). The only CONTINUE interpretation available, *Taroo explained the newly equipped functions to John*, corresponds to the forward centers Cf1. It is a CONTINUE interpretation because $Cb(4c) = Cb(4b)$ and also $Cb(4c) = Cp(4c)$. The RETAIN interpretation is less preferred and is defined by the fact that $Cb(4c) = Cb(4b)$, but $Cb(4c) \neq Cp(4c)$. In an informal experiment, (Walker, Iida, and Cote, 1994) verified the preference for CONTINUE empirically; when interpreting 4c, 27

⁵In Japanese, the EMPATHY LOCUS marks the entity who the speaker identifies with, or whose perspective the speaker takes (Kuno, 1976; Kuno and Kaburaki, 1977; Kameyama, 1985; Kameyama, 1988; Iida, 1992).

⁶The contra-indexing constraints integrated into BFP's centering algorithm for anaphora resolution eliminate the possibility that *Taroo* (or *John*) could have explained anything to himself..

subjects preferred the CONTINUE interpretation and 1 subject preferred the RETAIN interpretation ($Z = 13.24, p < .01$).

3 Open Issues in Centering

The previous section illustrated the centering definitions with constructed examples, but several issues arise as soon as one attempts to develop empirical support for the theory through corpus-based or psycholinguistic experiments. These issues roughly define five themes, extending from utterance-level issues such as the need for an algorithm to divide spontaneous speech into utterances for centering, to issues such as how centering interacts with global discourse structure. The chapters in the book are grouped into these five themes, and many papers provide detailed empirical studies that address multiple issues. The issues addressed within each theme are discussed in the remainder of this section.

3.1 Utterance Level Issues in Centering

The first theme is a set of issues about how the structure and representation of the utterance affect centering. Utterance level issues in centering include (1) making the definition of the REALIZE relation more specific, (2) determining the factors relevant to ordering the Cf list in English and other languages, (3) integrating centering with theories of semantic interpretation, (4) determining algorithms for dividing spontaneous speech into utterances for centering, and (5) determining how centering operates in sentences with coordinate and subordinate structures.

Both Cote (this volume) and Hudson-D’Zmura (this volume) explore issues with ranking forward-looking centers and the relationship of this issue to semantic theories that might underlie centering and affect what is REALIZED by an utterance.⁷ This work is important because the ranking of the Cf plays a critical role in centering: the ranking of the Cf(U_i) determines the Cb(U_{i+1}) (Constraint 3), and thus is the main determinant of which transition state holds between utterances. Thus Cf ranking also has a direct effect on work that attempts to test Rule 2.

GJW86 proposed that the factors that contribute to the Cf ranking include subjectness and pronominalization, with discourse entities that are pronominalized, or realized as subjects, ranked higher on the Cf. Kameyama proposed that entities realized by subjects are more highly ranked with respect to Cb establishment (Kameyama, 1988), but that only entities that were pronominalized in the previous

⁷For discussion relevant to the REALIZE relation see also Gundel’s (this volume) discussion of inferrables (Prince, 1981), and the discussion of poset and functional dependencies in both Hurewitz (this volume) and Birner (this volume).

utterance are candidates for the Cb. BFP, drawing on HPSG's subcategorization feature (Pollard and Sag, 1988), proposed ordering the Cf by obliqueness of grammatical role as shown in 3 above. (Gordon, Grosz, and Gilliom, 1993) provide some psycholinguistic evidence that suggests that syntactic role has an effect.

Cote (this volume) argues that Jackendoff's lexical conceptual structures (Jackendoff, 1990) are more predictive building blocks of local coherence, and, therefore, that lexical-conceptual primitives should make up the Cf-template for English. Cote specifies how BFP's ranking by grammatical function fails to account for specific types of zero pronominals in English, which can occur in the context of particular verbs such as *eat*, *call* and *see*. She argues that the objects of these verbs are represented in the lexical entry for the verb, as optional arguments, and that these optional arguments give rise to entities which must be represented on the Cf list for an utterance. Cote's argument is based on observable effects of various types of null objects in English, but she also briefly discusses cross-linguistic data and event reference.

Hudson-D'Zmura (this volume) presents work on specifying the relationship between lexical semantics and discourse structure in order to show how these types of linguistic representations restrict or control inference-making (Joshi and Weinstein, 1981); (Joshi and Weinstein, this volume). In contrast with earlier work that examined what features of surface utterances contribute to the prominence of the entities within an utterance and between utterances, Hudson-D'Zmura asks what might be a plausible, pragmatic, organizing principle and how such a principle would affect (1) the structure of lexical representations and (2) what may be projected to surface structure and in what configuration. Then she argues that the notion of control (Klaiman, 1991) provides the basis for a universal pragmatic principle, and that a basic set of predicates based on control can be used to decompose meaning and provide a representation of the event structure. She further argues that the notion of control for English captures our intuitions about intentionality of acts and is similar to the notion of EMPATHY in Japanese (Kameyama, 1985; Walker, Iida, and Cote, 1994).⁸

Hudson-D'Zmura experimentally tests her proposal about the role of control in discourse prominence by an experiment in which subjects first classify verbs according to whether they are high intentionality or low intentionality. Her experiments test perception verbs in the frame shown in 6 and 7:

(6) Dan saw Ben approaching the store.

(7) Dan scrutinized Ben approaching the store.

⁸See also Di Eugenio (this volume) and Turan (this volume) (Turan, 1995) for a discussion of how psychological verbs in Turkish and Italian seem to interact with centering in a way that is similar to empathy verbs in Japanese.

The results show, for example, that *see* is a low intentionality verb and *scrutinized* is a high intentionality verb. In a second experiment, Hudson-D’Zmura tested for differences in the interpretation of (8) depending on whether the subject had read (6) or (7):

(8) He went inside.

Hudson-D’Zmura’s results show that when the intentionality of the act is low, the noncenter *Ben* is chosen a greater percentage of the time as the co-specifier of the pronoun *he* in 8. Hudson-D’Zmura summarizes by comparing the event structure approach with that of Cote (this volume) and Turan (this volume).

Kameyama (this volume) addresses the issue of developing algorithms for dividing spontaneous speech or naturally-occurring written texts into the utterance units U_i on which centering is defined. Consider the naturally occurring excerpt from spoken conversation in 9 from (Walker and Prince, In Press):⁹

(9) We found out that uh what really happened was while she_i was getting ready for the date, she_i ran out of hair gel. And uh, that time she_i called [her_i sister]_j. And uh [her_i sister]_j’s answering machine] came on. And she_i yelled into it: it was an emergency for her_j to pick up the phone right away.... (Collected by B. Linson)

In (9), periods indicate one possible utterance level segmentation, but it is not clear how this decision is made. In naturally occurring speech, it is common to use conjunctions such as *and* to link clauses. Should each clause be treated as an utterance for the purpose of centering?

Passonneau, Hurewitz and Walker’s chapters assume an algorithm for utterance level segmentation of spontaneous speech. Passonneau’s algorithm is described in more detail in (Passonneau, 1994). Hurewitz proposes that an utterance is a finite clause, except that restrictive and medial relative clauses are part of the main clause. For spoken dialogue, both Hurewitz and Walker propose a working assumption that backchannels and utterances such as *I know* do not affect the centering data structures. Walker proposes that they are carried over by being implicitly realized, and Hurewitz proposes that such utterances are not counted as utterances for the purpose of centering.

Similar issues arise with utterance level segmentation of texts. For example, in discussing 10 from the novel *Wheels*, Walker points out that, if the Cf is ranked by grammatical function, as in BFP, all arguments in the *where*-clause in 10 are predicted to be of equal salience (Walker, 1989).

⁹Excerpt 9 is a naturally-occurring narrative from the TV show *Cops*. At the beginning of the excerpt, the discourse model contains both the policemen who are speaking, and a female discourse entity.

- (10) A housekeeper had brought a tray to his desk in the softly lighted study where, since 5 a.m., he had been alternately reading memoranda (mostly on special blue stationery which Ford vice-presidents used in implementing policy) and dictating crisp instructions into a recording machine.

Kameyama (this volume) proposes a set of rules for written sentences of different types, motivated by a number of examples from naturally occurring written discourses from the Brown corpus. The proposal is to break a complex sentence into a hierarchy of center-updating units, which supports an algorithm for assigning the preferred interpretation of a pronoun in its local context arbitrarily deep in the given sentence structure. In addition, Di Eugenio (this volume) discusses how subordinate clauses affect centering in Italian.

3.2 *Centering as a Cross-Linguistic Universal*

The second theme is the status of the rules and constraints of centering as cross-linguistic universals. The issue that has received the most attention in applying centering cross-linguistically is how the ranking of the forward centers list varies from language to language. The search for cross-linguistic universal effects on Cf ranking has led to many interesting proposals. The original centering proposals were based on examples in English, and suggested that grammatical role and pronominalization were relevant factors in Cf ranking. However, since English is a fixed-word order language in which all pronominal forms are overt, it is usually difficult to distinguish ranking by grammatical role from ranking by the linear order in which discourse entities are realized in an utterance. In contrast, many languages, such as Japanese, have both null and overt forms of pronouns and languages such as Turkish are ‘free word order’ languages. Thus in these languages, linear order cannot be used to order discourse entities realized by null forms.¹⁰

Based on their work on Japanese, Walker, Iida, and Cote (1994) proposed that the Cf ranking is language-specific depending on the means the language provides for indicating discourse function. Furthermore, they suggested that the ability to capture cross-language variation in a single parameter was an advantage of the centering framework (Walker, Iida, and Cote, 1990; Walker, Iida, and Cote, 1994). This work built on Kameyama’s proposals about rankings for Cb-Establishment, and the proposed Cf ranking for Japanese incorporates the effect of Japanese zero topics, topic marking and empathy marking.

Iida (this volume) tests the ranking proposed in (Walker, Iida, and Cote, 1994) on a corpus of Japanese newspaper articles. She also investigates the interaction of higher level discourse structures with the use of zero pronominals in Japanese.

¹⁰For additional discussion of language-specific effects, see (Kameyama, 1985; Yongkyoon, 1991; Rambow, 1993; Prince, 1994).

Iida's chapter applies centering to detecting topic shifts and examines factors that contribute to maintaining discourse coherence during topic shifts. Iida shows that the speaker cues the hearer when the center shifts so that hearers can adjust their attentional state. The primary cues observed in the data are constraints based on lexical information, such as selectional, aspectual and agreement information. Furthermore, Iida claims that a discourse entity that was never realized as the Cb cannot be interpreted as the referent of a zero pronoun, even if it is a potential candidate by semantic criteria. She suggests that these factors indicate that it might be possible to use centering as a cue to infer higher level discourse structure (see also Passonneau (this volume) for further discussion).

Di Eugenio (this volume) examines the functions that null and overt pronominal subjects perform in Italian. In previous work, she proposed that the alternation of null and overt pronouns in subject position can be accounted for in terms of centering transitions (Di Eugenio, 1990). This chapter tests the previously proposed hypotheses against a corpus of naturally occurring data and discusses how factors such as possessives and subordinate clauses affect centering. Di Eugenio's analysis leads to a proposal to refine the CONTINUE transition to distinguish between a CONTINUE that follows a RETAIN, and a CONTINUE that follows any of the other centering transitions, as will be discussed in more detail in section 3.4 below. Di Eugenio also discusses the factors that determine when pronominal subjects can be used to refer to entities which don't appear on the forward looking center list of the previous utterance.

Turan (this volume) examines the distribution of null and overt pronominals and full NPs, in naturally occurring Turkish texts. She argues that the Cf ranking in Turkish is associated not with word order, but with either grammatical relation or a semantic role hierarchy.¹¹ Turan provides evidence that subjecthood is critical for the Cf ranking in Turkish. Strong evidence for ranking subjects higher than objects comes from a prevalent strategy in Turkish discourse; if an entity in Turkish is realized in object position, it cannot be realized with a null subject in the subsequent utterance, it has to be realized with a full NP. Once an entity is realized with a full NP in subject position, it can be realized with a null subject in subsequent utterances.¹²

Along with Iida, Di Eugenio and Hudson-D'Zmura, Turan notes the importance of specifying how point of view, and syntactic and sortal restrictions on discourse entities interact with centering. Turan proposes two new rules as cross-linguistic universals: a CENTER PROMOTION RULE that incorporates findings about subjectness with the role of syntactic and semantic constraints, and a DISCOURSE POINT OF VIEW RULE that incorporates findings about how point of view affects centering. See also

¹¹Hoffman (this volume) examines the interaction of word order and information structure in Turkish, providing support for Turan's claims about Cf ranking in Turkish, as will be discussed in more detail below.

¹²This replicates Brennan's findings for English monologues: an entity first realized in object position cannot be pronominalized in the next utterance (Brennan, 1995).

(Turan, 1995).

3.3 *Information Structure and Centering*

The third theme is the relationship between information structure and centering. The notion of information structure is based on the assumption of contemporary discourse theory that the syntactic choices that a speaker makes are affected by discourse level factors such as the speaker's assumptions about what the hearer knows or could be expected to be thinking about (Prince, 1985; Prince, 1986). The function of these choices is to package the information in the utterance for particular pragmatic and semantic effects. An open question in centering is how the centering rules and constraints interact with information structure concepts such as GIVEN, NEW, TOPIC, COMMENT, THEME, and RHEME (Prince, 1981; Horn, 1986; Hajicova and Vrbova, 1982; Kuno, 1987; Danes, 1974). The chapters by Hoffman, Grosz and Ziv, Hurewitz, and Birner investigate the relationship between centering and sentential forms that mark information structure.

Hoffman (this volume) investigates the interaction between centering and speakers' choices of word order in Turkish, a 'free word order' language. Word order in Turkish is used to express the information structure of a sentence, i.e. pragmatic notions such as topic, focus, and backgrounding. Hoffman argues that centering and information structure play different roles in discourse processing. Her claim is that the information structure of a sentence instructs the hearer on how to update his/her discourse model with the information in the current sentence alone, while centering serves to link the sentence to the prior context.

Hoffman's corpus study shows that the Cb is often placed in the sentence-initial, topic position in Turkish regardless of whether this topic is the subject or a scrambled object. Based on the corpus study, Hoffman shows that word order in Turkish cannot determine the Cf ranking of the discourse referents in a utterance. In the corpus, speakers tend to keep talking about the subject of the previous utterance in the next utterance regardless of the previous utterance's word order. Thus, Hoffman argues, supporting Turan (this volume), that the Cf ranking in Turkish is associated not with word order, but with a grammatical relation (or a semantic role) hierarchy.

Grosz and Ziv examine how centering interacts with the sentential structure called RIGHT DISLOCATION in both English and Hebrew. RIGHT DISLOCATION is exemplified by 11:

(11) He₁ is here, Jim₁.

Grosz and Ziv argue that RIGHT DISLOCATION is planned speech. They propose that the function of RIGHT DISLOCATION is to organize the discourse when standard reference and discourse processing are not sufficient. It can be used to retrieve and

re-focus a previously centered entity, or to shift to an entity that is only situationally evoked. These two cases are unified under the notion that the entity is already present in the discourse context but is not sufficiently salient to warrant the use of a pronoun.

Hurewitz (this volume) uses centering transitions across utterances in a corpus-based study as a way of verifying the discourse function of the passive construction. She proposes that certain sentential constructions can be classified according to a CENTRALITY INDEX, a measure which is used to investigate whether certain constructions mark particular constituents as more likely to be linked to a preceding or subsequent utterance. Hurewitz compares spoken and written passive sentences to their active counterparts and finds evidence that the passive construction has different uses in the spoken and written form. In conversational spoken speech, passives are reliably more likely to have the CONTINUE transition than a control sample, and the CENTRALITY INDEX of spoken passives is higher than the control sample. This effect is not found in written text. On the other hand, written passives tend to be used reliably more often for what Hurewitz calls PARTIAL SHIFTS: utterances where the Cb is a subset of, or functionally dependent on, elements realized in the previous utterance. Finally, the utterance following written passives, but not spoken passives, are found to SMOOTH SHIFT more often than the control. This work indicates that spoken passives are highly coherent structures that often continue the Cb of the previous utterance, while written passives shift the center.

Birner (this volume) examines the interaction between centering and INVERSION, a syntactic structure in which a constituent that is the logical subject appears in a post-verbal position, while a canonically post-verb constituent appears clause-initially. An example of INVERSION is shown in italics in 12:

(12) We pulled off, and *right at the end of the exit was an Amoco.*

What is inverted is *an Amoco* and *right at the end of the exit* since the same propositional content expressed with canonical sentence structure would be *An Amoco was right at the end of the exit*. In previous work, Birner reported the results of a corpus analysis that showed showed that the preposed constituent of an English inversion must not represent less familiar information within the discourse than does the postposed constituent (Birner, 1992; Birner, 1994). Furthermore, what is relevant for the felicity of an inversion is more than simply whether or not an element has been previously evoked in the discourse; the corpus analysis suggests that discourse-familiarity is a gradient notion determined by a range of factors, including prior evocation, inferrability, and recency of mention.

Birner's previous work, however, made no predictions about the subset of the corpus in which both constituents represent either discourse-old or discourse-new information. In this chapter, Birner argues that speakers' utterances convey varying degrees of salience, and that this can be captured within centering by the Cf list ranking.

An examination of the corpus using centering to capture a salience ranking shows that when the information represented by the preposed and postposed constituents has been previously evoked at different points in the discourse, the element that has been mentioned most recently consistently appears in preposed position in the inversion. That is, more recently evoked information is treated as more familiar in the discourse than less recently evoked information.

Birner argues that, since the information presented in the preposed constituent is consistently more familiar within the discourse than that presented in the postposed constituent, the preposed constituent can be seen to consistently represent the Cb of the utterance, given that the Cb constitutes an utterance's primary link to the prior discourse. Thus, on Birner's analysis the notion of a backward-looking center provides a unified account of the distribution of inversion in discourse, which previously required at least two notions – discourse-old status and recency of mention.

3.4 The Role of Centering in Processing Models of Discourse

The fourth theme is the role of centering in processing models of discourse. Centering is formulated as a processing model because coherence is measured as the degree of processing required to interpret a discourse. The chapters by Gundel, Hudson-D'Zmura and Tanenhaus, and Brennan focus on the relationship between processing, choice of referring expression, and the perceived coherence of the discourse.

Gundel (this volume) attempts to integrate a theory of choice of referring expression proposed by (Gundel, Hedberg, and Zacharski, 1993), henceforth GHZ, with centering. In previous work, GHZ proposed a theory intended to explain the distribution and interpretation of noun phrase forms in natural language discourse. A major premise of GHZ is that different determiners and pronominal forms signal different cognitive statuses (information about location in memory and attention state), thereby serving as processing signals which assist the addressee in restricting the set of possible referents. GHZ and Centering theory make similar predictions about the distribution and interpretation of pronouns and full NPs in naturally occurring discourse. The two theories also complement one another in that GHZ is more general, covering a broader range of forms and statuses, whereas Centering theory provides an explicit algorithm for how an entity acquires the statuses that GHZ termed ACTIVATED and IN FOCUS.

Gundel suggests that a possible barrier to successful integration is the constraint that there is at most one Cb per clause, and she proposes that there are independent reasons for abandoning this constraint based on the distribution of pronouns in naturally occurring discourse. A tentative syntactic explanation is proposed for

the facts that originally motivated the constraint, by drawing on an intersentential version of Condition C of Chomsky's Binding Theory (Chomsky, 1980).

Hudson-D'Zmura and Tanenhaus (this volume) explicitly test the processing claims of centering with experiments using an on-line coherence judgment task. They present the results of four experiments on the use of pronouns and nouns in discourse that support the centering framework, as parameterized by BFP's Cf ranking. The experiments show that ambiguous pronouns referring to the backward-looking center were judged to be coherent more often and more quickly than ambiguous pronouns which did not refer to the backward-looking center, indicating that an immediate provisional interpretation was made on the basis of discourse structure. In addition, ambiguous pronouns were processed faster than explicit nouns when both were used to establish the backward-looking center. Finally, sentences with ambiguous pronouns that did not cospecify with the Cb took more time to process and were sometimes interpreted as referring to the backward-looking center even when this assignment was semantically implausible.

Brennan (this volume) argues that centering is a resource by which speakers and addressees can coordinate their attention moment by moment. Brennan first reviews relevant previous work on utterance comprehension and production that bear on centering as a processing theory. Then, Brennan presents new data from a corpus of dialogs about basketball games (Brennan, 1995), which focuses on the relationship between centering's ability to make **local** predictions about processing and the interaction of centering with global discourse structures. Brennan's chapter also considers centering's processing predictions for utterances with multiple pronouns and those in dialogues where centers are contributed by multiple speakers. On the basis of this analysis, she suggests that a plausible processing theory of the integration of centering with global discourse structure must model the activation and decay of discourse entities over time (cf. Walker's cache model (this volume), (Walker, 1996)).

Brennan's chapter also discusses psychological research that is relevant to determining the scope of application of the centering transition preferences (Rule 2). GJW86 state that sequences of continuations are to be preferred to sequences of retentions, and that sequences of retentions are preferred to sequences of shifts. Furthermore, they suggest that Rule 2 applies to the level of **pairs** of utterances. This formulation of Rule 2 suggests that, for interpretation, the discourse processor might refrain from assigning an interpretation to an utterance with anaphoric referring expressions until a whole segment, or some sequence longer than a single utterance, is completed (Grosz and Sidner, this volume). After a sequence of some length, individual utterances would be interpreted in such a way as to maximize coherence over the whole sequence. GJW95 however suggest that this formulation of Rule 2 simply predicts that some sequences will produce a higher inference load than others. This would mean that Rule 2 cannot be used to make predictions about

anaphoric interpretation.¹³

An alternative application of Rule 2, suggested by BFP, is to apply it on an utterance by utterance basis, so that anaphora resolution can be done on an utterance by utterance basis. As Brennan notes (Brennan, this volume), this approach is plausible because psychological research has shown that both human sentence production and interpretation takes place on a phrase by phrase basis. If centering has an effect on human sentence production, it would seem likely that it would operate at the same level. In addition, as discussed above, Hudson-D’Zmura and Tanenhaus’s experiments test aspects of Rule 2 with variations of discourse sequences in which the target sentence was either a CONTINUE or a SHIFT. They report that ambiguous pronouns in subject position were interpreted immediately as co-specifying the Cb of the previous utterance; that is the subjects interpreted these sentences immediately as realizing a CONTINUE transition based on the information available at that point.

This suggests that a promising avenue of research would be to extend our understanding of how the previous centering transition affects the current one. Di Eugenio (this volume) provides evidence that a CONTINUE following a RETAIN is not the same as a CONTINUE following another CONTINUE or a SMOOTH-SHIFT (see also (Turan, 1995)). Di Eugenio tests the hypothesis in 13 for Italian, which has both null and overt (strong) pronouns:

- (13) Typically, a null subject signals a CONTINUE and a strong pronoun signals a RETAIN or a SHIFT.

Di Eugenio finds that there are differences in the distribution of null and strong pronouns depending on whether utterances that realize CONTINUE transitions follow CONTINUE or SHIFT transitions, versus RETAIN transitions. Continuations that follow RETAIN transitions are just as likely to realize the subject with a strong pronouns as with a null pronoun, whereas continuations that follow CONTINUE or SHIFT transitions are more than ten times as likely to use a null pronoun. This is consistent with the idea that the preferred center, Cp, predicts which discourse entity will be the Cb of the following utterance. A RETAIN predicts that the Cb will change; if this change does not occur, then the speaker must use a strong pronoun to prevent the hearer from misinterpreting the utterance.¹⁴

¹³In addition, because empirical studies of centering show that the RETAIN transition is quite rare in naturally occurring discourse (see Hurewitz this volume, Passonneau this volume, Di Eugenio this volume), it will not be easy to test the claim that pairs of retentions are preferred over pairs of shifts by corpus analysis.

¹⁴Strube also posits that a SMOOTH-SHIFT following a RETAIN is more coherent than a CONTINUE following a retain (Strube, 1996). This analysis is based on simple assumptions about anaphora resolution processes; if the $Cp(U_i)$ predicts the $Cb(U_{i+1})$, then a pronoun in subject position of U_{i+1} should be immediately interpretable as realizing the $Cp(U_i)$, which will generate a SMOOTH-SHIFT transition.

3.5 Discourse Structure and Centering

Centering is formulated as *a theory that relates focus of attention, choice of referring expression, and perceived coherence of utterances, within a discourse segment* (Grosz, Joshi, and Weinstein, 1995), p. 204. The fact that the theory is only specified for utterances *within a discourse segment* leaves the issue of how centering interacts with global discourse structure completely open. The chapters by Passonneau, Roberts, and Walker explicitly address this issue.

The fact that centering is underspecified with respect to its interaction with global discourse structure makes it difficult to test centering on extended discourses. Extended discourses are likely to consist of multiple segments, but any claim of the theory cannot be tested on two utterances that span a discourse segment boundary. Furthermore, recent empirical work on discourse segmentation suggests that speakers may disagree on where segment boundaries are, either because they construct different mental representations of the segmentation of a discourse, or because segments are naturally defined at varying levels of granularity (Passonneau and Litman, 1993; Grosz and Hirschberg, 1992; Passonneau and Litman, 1994; Hearst, 1994). To illustrate the problem, consider the continuation in 14 of the discourse excerpt in 9 from (Walker and Prince, In Press):

- (14)it was an emergency for her_j to pick up the phone right away. [Her_i sister]_j not being home, she_i hung up. [Her_i sister]_j came home a short time later, heard [her_j messages]_m, heard [her_j sister]_i calling for help. She_j then called [her_j father]_n, who called the Milton police...

Because it is not clear when a new discourse segment is initiated, Walker and Prince present two different analyses of the sequence in 14, both shown below in 15. In one, 15b initiates a new discourse segment, which assumes that the Cb is **not** carried over from the previous segment (shown as Cb1), and in the other, 15b continues the current discourse segment (shown in Cb2).

- (15) a. [Her_i sister]_j not being home, she_i hung up.

Cb:	FEM-I
Cf:	[FEM-I, FEM-J] CONTINUE

- b. [Her_i sister]_j came home a short time later,

Cb1:	[?]	NO CB
Cb2:	FEM-I	CONTINUE
Cf:	[FEM-I, FEM-J]	

- c. 0_j heard [her_j messages],

Cb:	FEM-J
Cf:	[FEM-J, MESSAGES-M] SMOOTH-SHIFT

- d. 0_j heard [her_j sister]_i calling for help.

Cb: FEM-J
Cf: [FEM-J, FEM-I] CONTINUE

Walker and Prince discuss evidence that 15b is a new discourse segment, which includes the fact that the speaker's fundamental frequency (F0) at the end of utterance 15a is close to the bottom of the speaker's range (Hirschberg and Pierrehumbert, 1986; Pierrehumbert and Hirschberg, 1990), and that *her* in 15c is accented (Cahn, 1995; Nakatani, 1993). But without a clear specification of the interaction of centering with discourse segment boundaries, it is unclear whether in fact centering should be affected by segment boundaries at all (Prince, 1994). In 15, we see that a change in Cb is effected from 15b to 15c; if 15a is segment-initial, this is a Cb instantiation which is classified as a CONTINUE. However, it is unclear whether this change in Cb might have been predictable by the analysis in which 15a initiates a new segment.

Roberts (this volume) presents a model that integrates Grosz & Sidner's discourse structure theory with a dynamic theory of semantic interpretation related to those of Heim and Kamp (Heim, 1982). Roberts argues that this integration provides a more precise characterization of the locality relevant for centering and of the related notion of salience, while also capturing logical constraints on anaphora. She bases her arguments on three issues. The first issue is that centering does not include constraints on logical accessibility that it would need in order to account for the infelicity of discourses such as 16:

- (16) a. Every apprentice_x that tried to loose a bolt_y stripped it_y.
b. # It_y was defective.

The second issue is that centering does not represent discourse entities commonly referred to as inferrables (Prince, 1981), so that centering is underspecified with respect to how inferrables might be integrated into the discourse representation and function as cospecifics for anaphora. The third issue is that Heim's theory of discourse structure must be extended to model relative salience among discourse entities, as centering does.

Passonneau (this volume) uses quantitative data to examine the effect of segment boundaries on centering. She presents the results of two empirical studies focused on how local utterance processing relates to the global discourse context, and how centering interacts with the global context to constrain the surface form of referring expressions other than pronouns. The studies Passonneau presents make use of a corpus of spoken narratives, the *Pear Stories* (Chafe, 1980), which have been annotated by naive subjects with multi-utterance segments hypothesized to be constituent units of global structure, corresponding to speaker intentions (Grosz and Sidner, 1986) or to episodes of the narrated story (Polanyi, 1987). Passonneau first examines the correlation of centering transitions with the empirically derived segments, finding that the frequency of CONTINUE is lower for segment-initial utterances,

Seg _i	U _j	
6	28	And you think “Wow, this little boy’s _i probably going to come and see the pears, 29a and he _i ’s going to take a pear or two, 29b and then go on <i>his_i</i> way.”
7	30	um but <i>the little boy_i</i> comes, (CONTINUE)
	31	and uh he _i doesn’t want just a pear,
	32	<i>he_i</i> wants a whole basket.
8	33	So <i>he_i</i> puts the bicycle down, (CONTINUE)
	34	and he _i .. you wonder how he _i ’s going to take it with this.

Figure 2: Excerpt from (Passonneau and Litman, 1994) where the lines indicate empirically verified discourse segments.

while the frequency of both types of SHIFT transitions is higher for segment initial utterances. However, Passonneau shows that it would be difficult to use centering transitions alone to predict segment boundaries; while SHIFT transitions occur more frequently in segment-initial utterances, they also occur quite frequently within discourse segments. Thus, from this analysis it seems clear that centering transitions do not directly reflect segmental structure.

In a second study, Passonneau examines the informativeness of discourse anaphoric noun phrases relative to the same segmentation data. Passonneau finds that there are two discourse structure factors that correlate with OVERSPECIFIED NPs, NPs that are used in a context in which a pronoun would have been unambiguous. One discourse structure factor is whether the utterance that realizes the NP is a segment-initial utterance; nearly one third of OVERSPECIFIED NPs that occur in a different segment from their most recent cospecifier occur at a segment onset. The second factor concerns what Passonneau calls intra-segmental attentional shifts; these shifts are hypothesized shifts in attention that occur within a discourse segment, which are correlated with changes in temporal aspect or shifts in discourse reference time.

Passonneau’s findings about the distribution of overspecified NPs also provide support for a suggestion of Gundel (this volume). Gundel proposes that the acceptability of OVERSPECIFIED NPs depends on whether the utterance can be seen as initiating a new discourse segment. Gundel presents the contrasting discourses in 17 and 18, based on examples from GJW86:

- (17) a. Susan gave Betsy a pet hamster.
b. She reminded her that hamsters were quite shy.
c. /?And then Susan laughed.

- (18) a. Susan gave Betsy a pet hamster.

- b. She reminded her that hamsters were quite shy.
- c. And then Susan left.

Gundel argues that *Susan* in utterance 17c is OVERSPECIFIED and hence infelicitous, but that because 18c can be interpreted as initiating a new discourse segment, the OVERSPECIFIED NP in 18c is felicitous, and there is no increase in processing load, as would be suggested by Hudson-D’Zmura and Tanenhaus’s results (this volume). Thus judgments as to the felicity of a full NP for realizing the Cb depend on the ability of the hearer to view the utterance that contains the NP as initiating a new discourse segment.

In sum, both of Passoneau’s studies suggest that attentional state as defined by centering transitions and intentional structure are poorly correlated. Passoneau goes on to propose a model for integrating centering with global processing to provide a more uniform model of discourse anaphoric reference, and she concludes by hypothesizing how centering and informational constraints relate to inferences about relations among segments.

Walker (this volume) also considers the question of how centering interacts with the global structures of Grosz and Sidner’s theory of discourse structure. Walker notes that centering is defined on the basis of local features of utterances and then argues that the difficulty with integrating centering with global discourse structure arises from three features of Grosz and Sidner’s stack model: (1) the global properties of attentional state are modeled with a stack; (2) the stack model cannot be easily related to well-known facts about human sentence processing and limitations on human working memory; (3) the operations on the stack are directly determined by relations between intentions. She proposes that these problems can be eliminated by replacing the stack model with an alternate model of attentional state, the cache model (Walker, 1996).

After presenting the cache model and showing how it is easily integrated with BFP’s centering algorithm, Walker discusses several types of data to support her argument. First she discusses evidence that shows that the cache model can handle FOCUS POPS, which were believed to provide strong support for the stack model. Second, she discusses the distribution of centering transitions for segment initial utterances in comparison with a random sample of utterances. The fact that centers are carried over segment boundaries in over 60% of the cases supports Walker’s argument that centers are carried over segment boundaries by default, and argues that centering must be integrated with a model of global focus. Finally, Walker defines a set of intentional structure configurations and shows that for every type of intentional structure configuration, centers can be continued over discourse segment boundaries, and that both pronouns and full NPs can be used for continuations across segment boundaries. Thus intentional structure configurations do not appear to directly determine the form of referring expressions. Then, Walker argues that this data is consistent with the cache model since the cache model predicts a loose

correlation between intentional structure and attentional state.

Walker's results provide further support for Passonneau's analysis; in addition Walker suggests that other kinds of semantic relations may be more predictive for centering. In particular, a contrastive relation between adjacent utterances may be predictive of OVERSPECIFIED NPs, as is suggested by the occurrence of *but* in utterance 30 in Figure 2 (see also (Fox, 1987); Di Eugenio (this volume)).

4 Summary

We provided a brief overview of the rules and constraints of centering that are used in the chapters in the book and then grouped the open issues in centering into a set of five general themes: (1) utterance level issues in centering; (2) centering as a crosslinguistic universal; (3) information structure and centering; (4) the role of centering in processing models of discourse; (5) discourse structure and centering. Section 3 discussed each theme and outlined how each chapter provides detailed studies and empirical evidence addressing these themes. We hope that this book will stimulate further theoretical and empirical work in centering and improve our understanding of centering and related discourse phenomena.

References

- Barwise, Jon. 1988. The situation in logic-iv: On the model theory of common knowledge. Technical Report No. 122, CSLI.
- Birner, Betty. 1992. *Inversion in English*. Ph.D. thesis, Northwestern University.
- Birner, Betty J. 1994. Information status and word order: An analysis of english inversion. *Language*, 70:233–259.
- Brennan, Susan E. 1995. Centering attention in discourse. *Language and Cognitive processes*, 10(2):137–167.
- Brennan, Susan E., Marilyn Walker Friedman, and Carl J. Pollard. 1987. A centering approach to pronouns. In *Proc. 25th Annual Meeting of the ACL, Stanford*, pages 155–162.
- Cahn, Janet. 1995. The effect of intonation on pronoun referent resolution. In *ACL95*.
- Chafe, Wallace L. 1980. *The Pear Stories: Cognitive, Cultural and Linguistic Aspects of Narrative Production*. Ablex, Norwood N.J.
- Chomsky, Noam. 1980. On binding. *Linguistic Inquiry*, 11:1–46.
- Clark, Herbert H. and Catherine R. Marshall. 1981. Definite reference and mutual knowledge. In Joshi, Webber, and Sag, editors, *Elements of Discourse Understanding*. CUP, Cambridge, pages 10–63.
- Danes, F. 1974. *Papers on Functional Sentence Perspective*. Academia, Prague.

- Di Eugenio, Barbara. 1990. Centering theory and the Italian pronominal system. In *COLING90: Proc. 13th International Conference on Computational Linguistics, Helsinki*, pages 270–275.
- Fox, Barbara A. 1987. *Discourse Structure and Anaphora: Written and Conversational English*. Cambridge University Press.
- Gordon, Peter C., Barbara J. Grosz, and Laura A. Gilliom. 1993. Pronouns, names and the centering of attention in discourse.
- Grosz, Barbara J. 1977. The representation and use of focus in dialogue understanding. Technical Report 151, SRI International, 333 Ravenswood Ave, Menlo Park, Ca. 94025.
- Grosz, Barbara J. and Julia B. Hirschberg. 1992. Some intonational characteristics of discourse structure. In *ICSLP*.
- Grosz, Barbara J., Aravind K. Joshi, and Scott Weinstein. 1983. Providing a unified account of definite noun phrases in discourse. In *Proc. 21st Annual Meeting of the ACL, Association of Computational Linguistics*, pages 44–50.
- Grosz, Barbara J., Aravind K. Joshi, and Scott Weinstein. 1986. Towards a computational theory of discourse interpretation. Unpublished Manuscript.
- Grosz, Barbara J., Aravind K. Joshi, and Scott Weinstein. 1995. Towards a computational theory of discourse interpretation. *Computational Linguistics*.
- Grosz, Barbara J. and Candace L. Sidner. 1986. Attentions, intentions and the structure of discourse. *Computational Linguistics*, 12:175–204.
- Gundel, Jeanette, Nancy Hedberg, and Ron Zacharski. 1993. Cognitive status and the form of referring expressions in discourse. *Language*, 69(2):274–307.
- Hajicova, Eva and Jarka Vrbova. 1982. On the role of the hierarchy of activation in the process of natural language understanding. In *COLING82: Proc. 9th International Conference on Computational Linguistics, Prague*, pages 107–113.
- Hearst, Marti. 1994. Text tiling: A quantitative approach to discourse segmentation. In *ACL94*.
- Heim, Irene. 1982. *The Semantics of Definite and Indefinite Noun Phrases*. Ph.D. thesis, University of Massachusetts, Amherst.
- Hirschberg, Julia and Janet B. Pierrehumbert. 1986. The intonational structuring of discourse. In *Proc. 24th Annual Meeting of the ACL, Association of Computational Linguistics*, pages 136–14.
- Hobbs, Jerry R. 1985. On the coherence and structure of discourse. Technical Report CSLI-85-37, Center for the Study of Language and Information, Ventura Hall, Stanford University, Stanford, CA 94305.
- Horn, Laurence R. 1986. Presupposition, theme and variations. In *Chicago Linguistic Society*, 22, pages 168–192.
- Hudson-D’Zmura, Susan B. 1988. *The Structure of Discourse and Anaphor Resolution: The discourse Center and the Roles of Nouns and Pronouns*. Ph.D. thesis, University of Rochester.
- Iida, Masayo. 1992. *Context and Binding in Japanese*. Ph.D. thesis, Stanford University, Linguistics Department.
- Jackendoff, Ray S. 1990. *Semantic Structures*. MIT Press, Cambridge Mass.
- Joshi, Aravind K. and Steve Kuhn. 1979. Centered logic: The role of entity centered

- sentence representation in natural language inferencing. In *Proc. International Joint Conference on Artificial Intelligence*.
- Joshi, Aravind K. and Scott Weinstein. 1981. Control of inference: Role of some aspects of discourse structure - centering. In *Proc. International Joint Conference on Artificial Intelligence*, pages 385–387.
- Kameyama, Megumi. 1985. *Zero anaphora: the case of Japanese*. Ph.D. thesis, Stanford University.
- Kameyama, Megumi. 1988. Japanese zero pronominal binding, where syntax and discourse meet. In William Poser, editor, *Papers from the Second International Workshop on Japanese Syntax*. Stanford: CSLI, pages 47–74. also available as University of Pennsylvania Tech Report MS-CIS-86-60.
- Klaiman, M. H. 1991. Control and grammar. *Linguistics*, 29:623–651.
- Kuno, Susumu. 1976. Subject, theme and speaker's empathy: A reexamination of relativization phenomena. In C. Li, editor, *Subject and Topic*. Academic Press, New York, pages 417–444.
- Kuno, Susumu. 1987. *Functional Syntax*. Chicago University Press, Chicago, IL, USA.
- Kuno, Susumu and Etsuko Kaburaki. 1977. Empathy and syntax. *Linguistic Inquiry*, 8:627–672.
- Nakatani, Christine H. 1993. Accenting on pronouns in spontaneous narrative. In *ESCA Workshop on Prosody*.
- Passonneau, Rebecca J. 1994. Protocol for coding discourse referential noun phrases and their antecedents. Technical report, Columbia University.
- Passonneau, Rebecca J. and Diane Litman. 1993. Intention-based segmentation. In *Proceedings of the 31st Meeting of the Association of Computational Linguistics*.
- Passonneau, Rebecca J. and Diane Litman. 1994. Empirical analysis of three dimension of spoken discourse: Segmentation, coherence and linguistic devices. In Donia Scott and Eduard Hovy, editors, *Burning Issues in Discourse*.
- Pierrehumbert, Janet and Julia Hirschberg. 1990. The meaning of intonational contours in the interpretation of discourse. In *Intentions in Communication*, pages 271–313.
- Polanyi, Livia. 1987. The linguistic discourse model: Towards a formal theory of discourse structure. Technical Report 6409, Bolt Beranek and Newman, Inc., Cambridge, Mass.
- Pollard, Carl J. and Ivan A. Sag. 1988. *Information-Based Syntax and Semantics*. CSLI Lecture Notes: Chicago University Press, Chicago, Illinois.
- Prince, Ellen F. 1978. On the function of existential presupposition in discourse. In *Papers from 14th Regional Meeting*. CLS, Chicago, IL, pages 362–376.
- Prince, Ellen F. 1981. Toward a taxonomy of given-new information. In *Radical Pragmatics*. Academic Press, pages 223–255.
- Prince, Ellen F. 1985. Fancy syntax and shared knowledge. *Journal of Pragmatics*, pages 65–81.
- Prince, Ellen F. 1986. On the syntactic marking of the presupposed open proposition. *Proceedings of the 22nd Annual Meeting of the Chicago Linguistic Society*.
- Prince, Ellen F. 1994. Subject prodrop in yiddish. In P. Bosch and R. van der Sandt,

- editors, *Focus and Natural Language Processing. Volume I. Intonation and Syntax*. Working Papers of the Institute for Logic and Linguistics, IBM Deutschland, pages 159–173.
- Rambow, Owen. 1993. Pragmatic aspects of scrambling and topicalization in German. In *Institute for Research in Cognitive Science Workshop on Centering Theory in Naturally-Occurring Discourse*.
- Reinhart, Tanya. 1981. Pragmatics and linguistics, an analysis of sentence topics. *Philosophica*, 27:53–94. Also 1982, IULC.
- Sidner, Candace L. 1979. Toward a computational theory of definite anaphora comprehension in English. Technical Report AI-TR-537, MIT.
- Sidner, Candace L. 1983. Focusing in the comprehension of definite anaphora. In M. Brady and R.C. Berwick, editors, *Computational Models of Discourse*. MIT Press.
- Strube, Michael. 1996. Functional centering. In *Proceedings of the 34th Annual Meeting of the Association of Computational Linguistics, ACL*.
- Turan, Umit Deniz. 1995. *Null vs. overt subjects in Turkish discourse: A Centering Analysis*. Ph.D. thesis, University of Pennsylvania.
- Walker, Marilyn A. 1989. Evaluating discourse processing algorithms. In *Proc. 27th Annual Meeting of the Association of Computational Linguistics*, pages 251–261.
- Walker, Marilyn A. 1996. Limited attention and discourse structure. *Computational Linguistics*, 21-2.
- Walker, Marilyn A., Masayo Iida, and Sharon Cote. 1990. Centering in Japanese discourse. In *COLING90: Proc. 13th International Conference on Computational Linguistics, Helsinki*, pages 1–8.
- Walker, Marilyn A., Masayo Iida, and Sharon Cote. 1994. Japanese discourse and the process of centering. *Computational Linguistics*, 20-2:193–232.
- Walker, Marilyn A. and Ellen F. Prince. In Press. A bilateral approach to givenness: a hearer-status algorithm and a centering algorithm. In Thorstein Fretheim and Jeanette Gundel, editors, *Reference and Referent Accessibility*. John Benjamins.
- Webber, Bonnie Lynn. 1978. *A Formal Approach to Discourse Anaphora*. Ph.D. thesis, Harvard University. Garland Press.
- Yongkyoon, N. 1991. A centering approach to the *[case][topic] restriction in Korean. *Linguistics*.