# Centering: A Framework for Modeling the Local Coherence of Discourse

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*This paper concerns relationships among focus of attention, choice of referring expression, and perceived coherence of utterances within a discourse segment. It presents a framework and initial theory of centering intended to model the local component of attentional state. The paper examines interactions between local coherence and choice of referring expressions; it argues that differences in coherence correspond in part to the inference demands made by different types of referring expressions, given a particular attentional state. It demonstrates that the attentional state properties modeled by centering can account for these differences.*

**Preface**

Our original paper (Grosz, Joshi, and Weinstein 1983) on centering claimed that certain entities mentioned in an utterance were more central than others and that this property imposed constraints on a speaker's use of different types of referring expressions. Centering was proposed as a model that accounted for this phenomenon. We argued that the coherence of discourse was affected by the compatibility between centering properties of an utterance and choice of referring expression. Subsequently, we revised and expanded the ideas presented therein. We defined various centering constructs and proposed two centering rules in terms of these constructs. A draft manuscript describing this elaborated centering framework and presenting some initial theoretical claims has been in wide circulation since 1986. This draft (Grosz, Joshi, and Weinstein 1986) has led to a number of papers by others on this topic and has been extensively cited, but has never been published.[1]

We have been urged to publish the more detailed description of the centering framework and theory proposed in Grosz, Joshi, and Weinstein (1986) so that an official version would be archivally available. The task of completing and revising this draft became more daunting as time passed and more and more papers appeared on centering. Many of these papers proposed extensions to or revisions of the theory and attempted to answer questions posed in Grosz, Joshi, and Weinstein (1986). It has become ever more clear that it would be useful to have a "definitive" statement of

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1 Early drafts of Grosz, Joshi, and Weinstein (1986) were in circulation from 1983. Some citations to other work have dates between 1983 and 1986. This work utilized these earlier drafts.

the original motivations for centering, the basic definitions underlying the centering framework, and the original theoretical claims. This paper attempts to meet that need. To accomplish this goal, we have chosen to remove descriptions of many open research questions posed in Grosz, Joshi, and Weinstein (1986) as well as solutions that were only partially developed. We have also greatly shortened the discussion of criteria for and constraints on a possible semantic theory as a foundation for this work.

## 1. Introduction

This paper presents an initial attempt to develop a theory that relates focus of attention, choice of referring expression, and perceived coherence of utterances within a discourse segment. The research described here is a further development of several strands of previous research. It fits within a larger effort to provide an overall theory of discourse structure and meaning. In this section we describe the larger research context of this work and then briefly discuss the previous work that led to it.

Centering fits within the theory of discourse structure developed by Grosz and Sidner (1986). Grosz and Sidner distinguish among three components of discourse structure: a linguistic structure, an intentional structure, and an attentional state. At the level of linguistic structure, discourses divide into constituent *discourse segments*; an embedding relationship may hold between two segments. The intentional structure comprises intentions and relations among them. The intentions provide the basic rationale for the discourse, and the relations represent the connections among these intentions. Attentional state models the discourse participants' focus of attention at any given point in the discourse. Changes in attentional state depend on the intentional structure and on properties of the utterances in the linguistic structure.

Each discourse segment exhibits both *local coherence*—i.e., coherence among the utterances in that segment—and *global coherence*—i.e., coherence with other segments in the discourse. Corresponding to these two levels of coherence are two components of attentional state; the local level models changes in attentional state within a discourse segment, and the global level models attentional state properties at the intersegmental level.

Grosz and Sidner argue that global coherence depends on the intentional structure. They propose that each discourse has an overall communicative purpose, the discourse purpose (DP); and each discourse segment has an associated intention, its discourse segment purpose (DSP). The DP and DSP are speaker intentions; they are correlates at the discourse level of the intentions Grice argued underlay utterance meaning (Grice 1969). If a discourse is multi-party (e.g., a dialogue), then the DSP for a given segment is an intention of the conversational participant who initiates that segment. Lochbaum (1994) employs collaborative plans (Grosz and Kraus 1993) to model intentional structure, and is thus able to integrate intentions of different participants. Satisfaction of the DSPs contributes to the satisfaction of the DP. Relationships between DSPs provide the basic structural relationships for the discourse; embeddings in the linguistic structure are derived from these relationships. The global coherence of a discourse depends on relationships among its DP and DSPs. Grosz and Sidner model the global-level component of the attentional state with a stack; pushes and pops of focus spaces on the stack depend on intentional relationships.

This paper is concerned with local coherence and its relationship to attentional state at the local level. Centering is proposed as a model of the local-level component of attentional state. We examine the interactions between local coherence and choices of referring expressions, and argue that differences in coherence correspond in part to the different demands for inference made by different types of referring expressions,

given a particular attentional state. We describe how the attentional state properties modeled by centering can account for these differences.

Three pieces of previous research provide the background for this work. Grosz (1977) defined two levels of focusing in discourse: global and immediate. Participants were said to be globally focused on a set of entities relevant to the overall discourse. These entities may either have been explicitly introduced into the discourse or sufficiently closely related to such entities to be considered implicitly in focus (Grosz 1981). In contrast, immediate focusing referred to a more local focusing process—one that relates to identifying the entity that an individual utterance most centrally concerns.

Sidner (1979) provided a detailed analysis of immediate focusing, including a distinction between the current discourse focus and potential foci. She gave algorithms for tracking immediate focus and rules that stated how the immediate focus could be used to identify the referents of pronouns and demonstrative noun phrases (e.g., "this party," "that party").

Joshi and Kuhn (1979) and Joshi and Weinstein (1981) provided initial results on the connection between changes in immediate focus and the complexity of inferences required to integrate a representation of the meaning of an individual utterance into a representation of the meaning of the discourse of which it was a part. To avoid confusion with previous uses of the term "focus" in linguistics, they introduced the centering terminology. Their notions of "forward-looking" and "backward-looking" centers correspond approximately to Sidner's potential foci and discourse focus.

In all of this work, focusing, whether global or immediate, was seen to function to limit the inferences required for understanding utterances in a discourse. Grosz and Sidner were concerned with the inferences needed to interpret anaphoric expressions of various sorts (e.g. pronouns, definite descriptions, ellipsis). They used focusing to order candidates; as a result the need for search was greatly reduced and the use of inference could be restricted to determining whether a particular candidate was appropriate given the embedding utterance interpretation. Joshi, Kuhn, and Weinstein were concerned with reducing the inferences required to integrate utterance meaning into discourse meaning. They used centering to determine an *almost* monadic predicate representation of an utterance in discourse; they then used this representation to reduce the complexity of inference.

In this paper, we generalize and clarify certain of Sidner's results, but adopt the "centering" terminology. We also abstract from Sidner's focusing algorithm to specify constraints on the centering process. We consider the relationship between coherence and inference load and examine how both interact with attentional state and choices in linguistic expression.

The remainder of this paper is organized as follows: in Section 2, we briefly describe the phenomena motivating the development of centering that this paper aims to explain. Section 3 provides the basic definitions of centers and related definitions needed to present the theoretical claims of the paper. In Section 4, we state the main properties of the centering framework and the major claims of centering theory. In Section 5, we discuss several factors that affect centering constraints and govern the centering rules given in Section 6. In Section 7, we discuss applications of the rules and their ability to explain several discourse coherence phenomena. In Section 8, we briefly outline the properties of an underlying semantic framework that are required by centering. Finally, in Section 9 we conclude with a brief comparison of centering with the research that preceded it and a summary of research that expands on Grosz, Joshi, and Weinstein (1986). In particular, Section 9 provides references to subsequent investigations of additional factors that control centering and examinations of its cross-linguistic applicability and empirical validity.

## 2. Phenomena To Be Explained

Discourses are more than mere sequences of utterances. For a sequence of utterances to be a discourse, it must exhibit coherence. In this paper, we investigate linguistic and attentional state factors that contribute to coherence among utterances within a discourse segment. These factors contribute to the difference in coherence between the following two discourse segments:[2]

(1)  a. John went to his favorite music store to buy a piano.

b. He had frequented the store for many years.

c. He was excited that he could finally buy a piano.

d. He arrived just as the store was closing for the day.


(2)  a. John went to his favorite music store to buy a piano.

b. It was a store John had frequented for many years.

c. He was excited that he could finally buy a piano.

d. It was closing just as John arrived.


Discourse (1) is intuitively more coherent than Discourse (2). This difference may be seen to arise from different degrees of continuity in what the discourse is about. Discourse (1) centers around a single individual, describing various actions he took and his reactions to them. In contrast, Discourse (2) seems to flip back and forth among several different entities.

More specifically, the initial utterance (a) in each segment could begin a segment about an individual named 'John' or one about John's favorite music store or one about the fact that John wants to buy a piano.

Whereas Discourse (1) is clearly about John, Discourse (2) has no single clear center of attention. Utterance (2b) seems to be about the store. If a reader inferred that utterance (2a) was about John, then that reader would perceive a change in the entity which the discourse seems to be about in going from (2a) to (2b); on the other hand, if the reader took (2a) to be about the store then in going to (2b), there is no change. In either case, in utterance (2c) John seems to be central, requiring a shift from utterance (2b), while the store becomes central again in utterance (2d), requiring yet another shift. This changing of 'aboutness' (in fact, flipping it back and forth) makes discourse (2) less coherent than discourse (1).

Discourses (1) and (2) convey the same information, but in different ways. They differ not in content or what is said, but in expression or how it is said. The variation in 'aboutness' they exhibit arises from different choices of the way in which they express the same propositional content. The differences can only be explained, however, by looking beyond the surface form of the utterances in the discourse; different types of referring expressions and different syntactic forms make different inference demands on a hearer or reader. These differences in inference load underlie certain differences

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2 This example and the others in this paper are single-speaker texts. However, centering also applies to dialogue and multi-party conversations. Issues of the interaction between turn-taking and changes in centering status remain to be investigated.

in coherence. The model of local attentional state described in this paper provides a basis for explaining these differences.

Thus, the focus of our investigation is on interactions among choice of referring expression, attentional state, the inferences required to determine the interpretation of an utterance in a discourse segment, and coherence. Pronouns and definite descriptions are not equivalent with respect to their effect on coherence. We conjecture that this is so because they engender different inferences on the part of a hearer or reader. In the most pronounced cases, the wrong choice will mislead a hearer and force backtracking to a correct interpretation.[3] The following variations of a discourse sequence illustrate this problem and provide additional evidence for our conjecture.

(3) a. Terry really goofs sometimes.

    b. Yesterday was a beautiful day and he was excited about trying out his new sailboat.

    c. He wanted Tony to join him on a sailing expedition.

    d. He called him at 6 AM.

    e. He was sick and furious at being woken up so early.

By using a pronoun to refer to Tony in utterance (e) the speaker may confuse the hearer. Through utterance (d) Terry has been the center of attention, and hence is the most likely referent of "he" in utterance (e). It is only when one gets to the word "sick" that it is clear that it must be Tony and not Terry who is sick, and hence that the pronoun in utterance (e) refers to Tony not Terry. A much more natural sequence results if "Tony" is used, as the sequence (4a)–(4e) illustrates.

(4) a. Terry really goofs sometimes.

    b. Yesterday was a beautiful day and he was excited about trying out his new sailboat.

    c. He wanted Tony to join him on a sailing expedition.

    d. He called him at 6 AM.

    e. Tony was sick and furious at being woken up so early.

    f. He told Terry to get lost and hung up.

    g. Of course, he hadn't intended to upset Tony.

In Discourse (4), utterances (f) and (g) exhibit the same kind of misdirection as do utterances (3d) and (3e) in Discourse (3). The focus has shifted from Terry to Tony in the short subsegment of utterances (e)–(f) so that use of "he" in (g) is confusing. This confusion is avoided in the sequence of Discourse (5).

(5) a. Terry really goofs sometimes.

    b. Yesterday was a beautiful day and he was excited about trying out his new sailboat.

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3 We presume utterances are processed in left-to-right order, and that speakers make initial assignments of referent and meaning that may have to be retracted if material coming later in the sentence conflicts.

    c. He wanted Tony to join him on a sailing expedition.

    d. He called him at 6 AM.

    e. Tony was sick and furious at being woken up so early.

    f. He told Terry to get lost and hung up.

    g. Of course, Terry hadn't intended to upset Tony.

We conjecture that the form of expression in a discourse substantially affects the resource demands made upon a hearer in discourse processing and through this influences the perceived coherence of the discourse. It is well known from the study of complexity theory that the manner in which a class of problems is represented can significantly affect the time or space resources required by any procedure that solves the problem. Here too we conjecture that the manner, i.e., linguistic form, in which a discourse represents a particular propositional content can affect the resources required by any procedure that processes that discourse. We use the phrase *inference load placed upon the hearer* to refer to the resources required to extract information from a discourse because of particular choices of linguistic expression used in the discourse. We conjecture that one psychological reflex of this inference load is a difference in perceived coherence among discourses that express the same propositional content using different linguistic forms.

    One of the tasks a hearer must perform in processing a discourse is to identify the referents of noun phrases in the discourse. It is commonly accepted, and is a hypothesis under which our work on centering proceeds, that a hearer's determination of noun phrase reference involves some process of inference. Hence a particular claim of centering theory is that the resource demands of this inference process are affected by the *form of expression* of the noun phrase. In Section 7, we discuss the effect on perceived coherence of the use of pronouns and definite descriptions by relating different choices to the inferences they require the hearer or reader to make.

## 3. Basic Center Definitions

We use the term *centers* of an utterance to refer to those entities serving to link that utterance to other utterances in the discourse segment that contains it. It is an utterance (i.e., the uttering of a sequence of words at a certain point in the discourse) and not a sentence in isolation that has centers. The same sentence uttered in different discourse situations may have different centers. Centers are thus discourse constructs. Furthermore, centers are semantic objects, not words, phrases, or syntactic forms.

    Each utterance U in a discourse segment (DS) is assigned a set of *forward-looking centers*, $C_f(U, DS)$; each utterance other than the segment initial utterance is assigned a single *backward-looking center*, $C_b(U, DS)$. To simplify notation, when the relevant discourse segment is clear, we will drop the associated DS and use $C_b(U)$ and $C_f(U)$.

    The backward-looking center of utterance $U_{n+1}$ connects with one of the forward-looking centers of utterance $U_n$. The connection between the backward-looking center of utterance $U_{n+1}$ and the forward-looking centers of utterance $U_n$ may be of several types. To describe these types, we need to introduce two new relations, *realizes* and *directly realizes*, that relate centers to linguistic expressions.

    We will say that

        U *directly realizes c*

if U is an utterance of some phrase[4] for which $c$ is the semantic interpretation. *Realizes* is a generalization of *directly realizes*. This generalization is important for capturing certain regularities in the use of definite descriptions and pronouns.

The precise definition of

U *realizes c*

depends on the semantic theory one adopts.[5] One feature that distinguishes centering from other treatments of related discourse phenomena is that the realization relation combines syntactic, semantic, discourse, and intentional factors. That is, the centers of an utterance in general, and the backward-looking center specifically, are determined on the basis of a combination of properties of the utterance, the discourse segment in which it occurs, and various aspects of the cognitive state of the participants of that discourse.

Thus, for a semantic theory to support centering, it must provide an adequate basis for computing the realization relation. For example, *NP directly realizes c* may hold in cases where *NP* is a definite description and $c$ is its denotation, its value-free interpretation (discussed in Section 8), or an object related to it by "speaker's reference" (Kripke 1977). More importantly, when *NP* is a pronoun, the principles that determine the $c$'s for which it is the case that *NP directly realizes c* do not derive exclusively from syntactic, semantic, or pragmatic factors. They are principles that must be elicited from the study of discourse itself. An initial formulation of some such principles is given in Section 8.[6]

The forward-looking centers of $U_n$ depend only on the expressions that constitute that utterance; they are not constrained by features of any previous utterance in the segment. The elements of $C_f(U_n)$ are partially ordered to reflect relative prominence in $U_n$. In Section 5, we discuss a number of factors that may affect the ordering on the elements of $C_f$. The more highly ranked an element of $C_f(U_n)$, the more likely it is to be $C_b(U_{n+1})$. The most highly ranked element of $C_f(U_n)$ that is realized in $U_{n+1}$ is the $C_b(U_{n+1})$. Because $C_f(U_n)$ is only partially ordered, some elements may, from $C_f(U_n)$ information alone, be equally likely to be $C_b(U_{n+1})$. In such cases, additional criteria are needed for deciding which single entity is the $C_b(U_{n+1})$. Some recent psycholinguistic evidence suggests that the syntactic role in $U_{n+1}$ may determine this choice (Gordon, Grosz, and Gilliom 1993).

In the remainder of the paper we will use a notation such that the elements of $C_f$ are ranked in the order in which they are listed.[7] In particular, for presentational

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4 U need not be a full clause. We use U here to stress again that it is the utterance, not the string of words.

5 In the original manuscript, we defined *realize* in terms of situation semantics (Barwise and Perry 1983) and said the relation held "if either $c$ is an element of the situation described by the utterance U or $c$ is directly realized by some subpart of U." We discuss this further in Section 7.

6 In the examples in this paper, we will be concerned with the realization relationship that holds between a center and a singular definite noun phrase; i.e., cases where an NP *directly realizes* a center $c$. Several extensions to the theory presented here are needed to handle plural, quantified noun phrases and indefinites. It is also important to note that not all noun phrases in an utterance contribute centers to $C_f(U)$ and not only noun phrases do so. More generally, events and other entities that are more often directly realized by verb phrases can also be centers, whereas negated noun phrases typically do not contribute centers; the study of these issues is, however, beyond the scope of this paper.

7 To simplify the presentation in the remainder of this paper, we will assume in most of the discussion that there is a total order with strict ordering between any two elements; at those places where the partial ordering makes a significant difference we will discuss that.

purposes, we will use the following schematic to refer to the centers of utterances in a sequence:

> For $U_n$: $C_b(U_n)$ = a, $C_f(U_n)$ = $(e_1, e_2, \ldots e_p)$, a = $e_k$, for some k.

> For $U_{n+1}$: $C_b(U_{n+1})$ realizes $e_m$ and, for all j, j < m, $e_j$ is not realized in $U_{n+1}$; i.e., $e_m$ is realized in $U_{n+1}$, and no higher ranked $e_j$ is realized in $U_{n+1}$.

Finally, we also define three types of transition relations across pairs of utterances.

1.  CENTER CONTINUATION: $C_b(U_{n+1})$= $C_b(U_n)$, and this entity is the most highly ranked element of $C_f(U_{n+1})$. In this case, $C_b(U_{n+1})$ is the most likely candidate for $C_b(U_{n+2})$; it continues to be $C_b$ in $U_{n+1}$, and continues to be likely to fill that role in $U_{n+2}$.

2.  CENTER RETAINING: $C_b(U_{n+1})$ = $C_b(U_n)$, but this entity is not the most highly ranked element in $C_f(U_{n+1})$. In this case, $C_b(U_{n+1})$ is not the most likely candidate for $C_b(U_{n+2})$; although it is retained as $C_b$ in $U_{n+1}$, it is not likely to fill that role in $U_{n+2}$.

3.  CENTER SHIFTING: $C_b(U_{n+1}) \neq C_b(U_n)$.

The coherence of a segment is affected by the kinds of centering transitions engendered by a speaker's choices of linguistic realizations in the utterances constituting the segment. Of particular concern are choices among (1) CONTINUATION of the center from one utterance not only to the next, but also to subsequent utterances; (2) RETENTION of the center from one utterance to the next; (3) SHIFTING the center, if it is neither retained nor continued.[8]

## 4. Claims of Centering Theory

The centering framework described above provides the basis for stating a number of specific claims about the relationship between discourse coherence, inference load, and choice of referring expression. Underlying these claims is the most fundamental claim of centering theory, that to the extent a discourse adheres to centering constraints, its coherence will increase and the inference load placed upon the hearer will decrease. We briefly list several major claims in this section, and elaborate on the evidence or motivation for each in subsequent sections.

- **A unique $C_b$:** Each $U_n$ has exactly one backward-looking center. It might be thought that a more general definition would allow for multiple backward-looking centers as well as multiple forward-looking centers. However, this is not the case, as we show in Section 5.

- **Ranking of $C_f$:** The $C_f$ elements are partially ordered according to a number of factors. Several of the factors posited to affect this ordering are discussed in Section 5, but the full set of factors remains to be determined. Ranking of elements in $C_f(U_n)$ guides determination of

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8 Shifting of the center does not in itself mark a discourse segment boundary. The center may shift within a single segment.

$C_b(U_{n+1})$; because $C_f(U_n)$ is only partially ordered, additional factors may constrain the choice.[9]

- **Centering constrains realization possibilities**: Rule 1, discussed in Section 6, stipulates one constraint centering imposes on realization. We expect that other such constraints exist.

- **Preferences among sequences of center transitions**: Rule 2, discussed in Section 6, hypothesizes a preference among types of transitions.

- **Primacy of partial information**: The information needed to compute a complete unique interpretation for an utterance may not be available until subsequent utterances are produced. Thus, as discussed in Section 8, to support centering, a semantic theory must support the construction of partial interpretations, in particular for elements of $C_f$.

- **Locality of $C_b(U_n)$**: The choice of a backward-looking center for an utterance $U_n$ is from the set of forward-looking centers of the previous utterance $U_{n-1}$. In this sense the $C_b$ is strictly local. $C_b(U_n)$ cannot be from $C_f(U_{n-2})$ or other prior sets of forward-looking centers.[10]

- **Centering is controlled by a combination of discourse factors**: Center determination is not solely a syntactic, semantic, or pragmatic process.

## 5. Factors Governing Centering

Before we can examine the linguistic features that contribute to an entity's being the backward-looking center of an utterance, it is necessary to provide support for the claim that there is only a single backward-looking center. In the definitions in Section 3, there is a basic asymmetry between the $C_f$, which is a set, and the $C_b$, which is a singleton. Sequences like those in (6) seem to suggest that there might be multiple $C_b$'s, analogous to the partially ordered set of $C_f$'s. A priori there is no reason to think that either Susan or Betsy alone is the $C_b$ of utterance (6b).

(6)    a.   Susan gave Betsy a pet hamster.

       b.   She reminded her that such hamsters were quite shy.

However, if we consider different subsequent utterances, it becomes clear that Susan and Betsy do not have an equivalent status in the second utterance. The ranking of the $C_f$'s matters. The variants (7)–(10) differ only in their choice of realization of Susan and Betsy, in particular in which is pronominalized and which is in subject position.

(7)    a.   Susan gave Betsy a pet hamster.

       b.   She reminded her that such hamsters were quite shy.

       c.   She asked Betsy whether she liked the gift.

(8)    a.   Susan gave Betsy a pet hamster.

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9 This point is connected with the discussion of partial ordering in Section 3.
10 It may appear that $C_b(U_n)$ comes from $C_f(U_{n-2})$ or prior sets of forward-looking centers, but then it is only because it is in $C_f(U_{n-1})$ also.

     b. She reminded her that such hamsters were quite shy.

     c. Betsy told her that she really liked the gift.

(9)  a. Susan gave Betsy a pet hamster.

     b. She reminded her that such hamsters were quite shy.

     c. Susan asked her whether she liked the gift.

(10)  a. Susan gave Betsy a pet hamster.

     b. She reminded her that such hamsters were quite shy.

     c. She told Susan that she really liked the gift.

If both Susan and Betsy were equally likely backward-looking centers in the second utterance of these sequences, then all of these variants would be equally good or, perhaps, there would be a preference for variants (7) and (9), which exhibit continuity of grammatical subject and object. However, this is not the case. There is a marked decrease in acceptability from version (7) to version (10), and for many people version (10) is completely unacceptable.

The problem is not merely a change from a pronoun back to a proper name, as this happens to the same extent in all four variants. It also cannot be attributed solely to a change from grammatical subject to grammatical object position, as variant (8) involves such a change and yet is better than variant (9), which does not. Rather, it must be the case that Susan is the $C_b$ at utterance (b) at each of the variants. Variants (9) and (10) can be shown to be worse than (7) and (8) because they violate the centering rules presented in the next section.

This example suggests that pronominalization and subject position are possible linguistic mechanisms for establishing and continuing some entity as the $C_b$. In the second utterance of these sequences, Susan is realized by a pronoun in subject position; 'she' is the $C_b$ of this utterance. Utterance (7c) continues Susan as $C_b$, whereas utterance (8c) merely retains her. Utterances like (8c) may be used to provide a basis for a shift in $C_b$.[11] However, this leaves open questions of the independence of syntactic role and pronominalization, and the predominance of either, for controlling centering.

The fact that being in subject position contributes in and of itself to the likelihood an entity will be the highest-ranked $C_f$ (i.e. likely to be the next $C_b$) can be seen by contrasting the following two sequences, which differ only in their final utterances:

(11)  a. Susan is a fine friend.

     b. She gives people the most wonderful presents.

     c. She just gave Betsy a wonderful bottle of wine.

     d. She told her it was quite rare. (Susan told Betsy)

     e. She knows a lot about wine. (Susan knows. . . )

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11 The effect of various linguistic constructions on center movement and the interactions of centering shifts with global discourse structure are active areas of research. Section 9 provides references to such work.

(12)  a.  Susan is a fine friend.

b.  She gives people the most wonderful presents.

c.  She just gave Betsy a wonderful bottle of wine.

d.  She told her it was quite rare. (Susan told Betsy)

e.  Wine collecting gives her expertise that's fun to share. (Susan's expertise)

In the (c) utterance of each sequence, Susan is the $C_b$. Either Susan or Betsy might be the referent of the subject pronoun in the fourth utterance; however, there appears to be a strong preference for Susan (i.e., for the reading "Susan told Betsy").[12] Because this preference might be attributable to parallelism, the last utterance in (12) provides a crucial test. If the $C_f$ ranking depended on pronominalization alone, the fourth utterance would allow either Susan or Betsy to be the highest-ranked $C_f$. Parallelism would suggest different preferences for the $C_b$(12e) in the two sequences. However, the preferred reading of the pronoun (respectively, "she" and "her") in utterance (e) of both sequences is Susan, who is realized in the subject position of the (d) utterances. This preference holds regardless of syntactic position in the (e) utterances. Thus, we can establish a preference for subject position. In other circumstances, however, as the examples below illustrate, the $C_b$ may be realized in other grammatical roles.

In the first clause of both utterances (13d) and (14d), the direct object is pronominalized; the pronoun "it" refers to the green plastic tugboat. In (13) taking the boat to be the highest ranked $C_f$ and hence the most likely referent for "the silly thing" in the second clause of utterance (d) yields a coherent and easily comprehensible discourse.[13] In (14), however, pragmatic information leads to a preference for the bear, not the boat, to be the referent of "the silly thing" in the last utterance; this preference is in conflict with the boat's being the most likely $C_b$. That (13) is a more coherent discourse than (14) can be explained on the basis of this difference.[14]

(13)  a.  Have you seen the new toys the kids got this weekend?

b.  Stuffed animals must really be out of fashion.

c.  Susie prefers the green plastic tugboat to the teddy bear.

d.  Tommy likes it better than the bear too, but only because the silly thing is bigger.

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12 Sequences in which a similar pronominalization pattern is used but in which the fourth utterance implies report of a dialogue (e.g., "She thanked her and told her she appreciated that the wine was quite rare.") may lead to interpretations in which the subject pronoun is taken as referring to Betsy; accentuation of the subject may also be used to achieve this result. The first of these suggests a strong interaction between dialogue verbs and centering, which is also apparent in direct-speech dialogue examples. The relationship between this kind of lexical–semantic influence over centering and that of so-called 'empathy' verbs, e.g., Kameyama (1985), Walker, Iida, and Cote (1994), remains to be determined. The second would appear to provide additional evidence for subject preference in centering, based on results of Hirschberg and Ward (1991) showing that accenting served to flip preferences (in their study from either strict-to-sloppy or sloppy-to-strict readings for anaphors in the antecedent clause in VP-ellipsis constructions).

13 For the sake of this argument, assume that children like bigger things more than smaller things. If this is not the case, then the argument merely flips which variants are more acceptable.

14 The discrepancy is even greater if "it" is used in the last utterance clause. However, one might attribute this to repetition of the use of "it" and so we have avoided the repeated use of a pronoun. We also note that "the silly thing" conveys additional information—roughly, the speaker's attitude toward the bear or tugboat (cf. Section 8).

(14)  a.  Have you seen the new toys the kids got this weekend?

     b.  Stuffed animals must really be out of fashion.

     c.  Susie prefers the green plastic tugboat to the teddy bear.

     d.  Tommy likes it better than the bear too, although the silly thing is bigger.

Thus, the discourses in (11)–(14) suggest that grammatical role is a major determinant of the ranking on the $C_f$, with SUBJECT > OBJECT(S) > OTHER. The effect of factors such as word order (especially fronting), clausal subordination, and lexical semantics, as well as the interaction among these factors are areas of active investigation; Section 9 again provides references to such work.

In summary, these examples provide support for the claim that there is only a single $C_b$, that grammatical role affects an entity's being more highly ranked in $C_f$, and that lower-ranked elements of the $C_f$ cannot be pronominalized unless higher-ranked ones are. Kameyama (1985) was the first to argue that grammatical role, rather than thematic role, which Sidner used, affected the $C_f$ ranking. Psycholinguistic research since 1986 (Hudson-D'Zmura 1988; Gordon, Grosz, and Gilliom 1993) supports the claims that there is a single $C_b$ and that grammatical role plays a determining role in identifying the $C_b$. It furthermore suggests that neither thematic role nor surface position is a determinant of the $C_b$. In contrast, both grammatical role and surface position were shown to affect the $C_f$ ordering. Although there are as yet no psycholinguistic results related to the effect of pronominalization on determining $C_b(U_{n-1})$, cross-linguistic work (Kameyama 1985; Prince and Walker 1995; Walker, Iida, and Cote 1994) argues that it plays such a role. Section 9 lists several papers appearing after Grosz, Joshi, and Weinstein (1986) that investigate factors affecting the $C_f$ ordering.

## 6. Constraints on Center Movement and Realization

The basic constraint on center realization is given by Rule 1, which is stated in terms of the definitions and schematic in Section 3.

**Rule 1**
If any element of $C_f(U_n)$ is realized by a pronoun in $U_{n+1}$, then the $C_b(U_{n+1})$ must be realized by a pronoun also.

In particular, this constraint stipulates that no element in an utterance can be realized as a pronoun unless the backward-looking center of the utterance is realized as a pronoun also.[15] Rule 1 represents one function of pronominal reference: the use of a pronoun to realize the $C_b$ signals the hearer that the speaker is continuing to talk about the same thing. Note that Rule 1 does not preclude using pronouns for other entities so long as the $C_b$ is realized with a pronoun. (This is illustrated in examples 7–10 in Section 5.) Psychological research (Gordon, Grosz, and Gilliom 1993; Hudson-D'Zmura 1988) and cross-linguistic research (Di Eugenio 1990; Kameyama 1985, 1986, 1988; Walker, Iida, and Cote 1990, 1994) have validated that the $C_b$ is preferentially realized by a pronoun in English and by equivalent forms (i.e., zero pronouns) in other languages.

The basic constraint on center movement is given by Rule 2.

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15 Rule 1 ignores certain complications that may arise if one of the forward-looking centers of $U_{n+1}$ is realized by a deictic pronoun.

**Rule 2**
*Sequences* of continuation are preferred over *sequences* of retaining; and sequences of retaining are to be preferred over sequences of shifting.

In particular, a pair continuations across $U_n$ and across $U_{n+1}$, represented as $Cont(U_n,U_{n+1})$ and $Cont(U_{n+1},U_{n+2})$ respectively, is preferred over a pair of retentions, $Ret(U_n,U_{n+1})$ and $Ret(U_{n+1},U_{n+2})$. The case is analogous for pair of retentions and a pair of shifts.

Rule 2 reflects our intuition that continuation of the center and the use of retentions when possible to produce smooth transitions to a new center provides a basis for local coherence. In a locally coherent discourse segment, shifts are followed by a sequence of continuations characterizing another stretch of locally coherent discourse. Frequent shifting leads to a lack of local coherence, as was illustrated by the contrast between Discourse (1) and Discourse (2) in Section 2. Thus, Rule 2 provides a constraint on speakers, and on natural-language generation systems. They should plan ahead to minimize the number of shifts. This rule does not have the same direct implementation for interpretation systems; rather it predicts that certain sequences produce a higher inference load than others. To empirically test the claim made by Rule 2 requires examination of differences in inference load of alternative multi-utterance sequences that differentially realize the same content.

Although several cross-linguistic studies have investigated Rule 2 (see Section 9), there are as yet no psycholinguistic results empirically validating it.

## 7. Applications of the Rules

The two centering rules along with the partial ordering on the forward-looking centers described in Section 5 constitute the basic framework of center management. These rules can explain a range of variations in local coherence.[16]

A violation of Rule 1 occurs if a pronoun is not used for the backward-looking center and some other entity is realized by a pronoun. Such a violation occurs in the following sequence presumed to be in a longer segment that is currently centered on John (cf. also examples (9) and (10) in Section 5):

(15)  a.  He has been acting quite odd. [$C_b$ = John = referent("he")]

     b.  He called up Mike yesterday. [$C_b$ = John = referent("he")]

     c.  John wanted to meet him urgently. [$C_b$ = John; referent("him") = Mike]

The violation of Rule 1 leads to the incoherence of the sequence. The only possible interpretation is that the "John" referred to in (15c) is a second person named "John," not the one referred to in the preceding utterances in (15); however, even under this interpretation the sequence is very odd. The next example illustrates that this effect is

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16 These rules and constraints have also been used by others as the basis for pronoun resolution algorithms based on centering. The earliest such attempt (Brennen, Friedman, and Pollard 1987) used the uniqueness and locality of $C_b$ constraints and ranked the $C_f$ by grammatical role; it employed a variant of Rule 2 in which the stated preferences on transitions were restricted to transitions between *individual pairs* of utterances (rather than the longer *sequences* in the original formulation) and used to decide between possible interpretations of pronouns. Section 9 provides references to other work on centering algorithms.

independent of the grammatical position of the $C_b$ and also demonstrates that Rule 1 operates independently of the type of centering transition.

(16)   a. John has been acting quite odd.

b. He called up Mike yesterday. [$C_b$ = John = referent("he")]

c. Mike was studying for his driver's test. [$C_b$ = Mike = referent("his")]

d. He was annoyed by John's call.

Without utterance (16c), this sequence, like the sequence in (15), is unacceptable unless it is possible to consider the introduction of a second person named "John." The intervening utterance (c) here provides for a shift in center from John to Mike, making the full sequence coherent.[17]

It is important to notice that Rule 1 constrains the realization of the most highly ranked element of the $C_f(U_n)$ *that is realized in* $U_{n+1}$ *given that pronominalization is used.* Obviously any entities realized in $U_n$ that are not realized in $U_{n+1}$, including the $C_b(U_n)$ as well as the highest ranked element of $C_f(U_n)$, do not affect the applicability of Rule 1. Likewise, if no pronouns are used, then Rule 1 is not applicable. Two particular ways in which such situations may hold have been noticed in previous research. Each leads to a different type of inference load on the hearer, both of which we believe relate to Rule 1; however, neither constitutes a violation of Rule 1. The resulting discourses are coherent, but the determination of local coherence (in the first case) or the detection of a global shift (in the second case) requires additional inferences.

The first case concerns realization of the $C_b$ by a nonpronominal expression. Rule 1 does not preclude using a proper name or definite description for the $C_b$ if there are no pronouns in an utterance. However, it appears that such uses are best when the full definite noun phrases that realize the centers do more than just refer. They convey some additional information, i.e., lead the hearer or reader to draw additional inferences. The hearer or reader not only infers that the $C_b$ has not changed even though no pronoun has been used, but also recognizes that the description holds of the old $C_b$. Sequences (17) and (18) are typical cases.[18]

(17)   a. My dog is getting quite obstreperous.

b. I took him to the vet the other day.

c. **The mangy old beast** always hates these visits.

(18)   a. I'm reading *The French Lieutenant's Woman.*

b. **The book, which is Fowles's best,** was a bestseller last year.

The second case concerns the use of a pronoun to realize an entity not in the $C_f(U_n)$; such uses are strongly constrained. The particular cases that have been identified involve instances where attention is shifted globally back to a previously centered entity (e.g. Grosz [1977], Reichman [1985]). In such cases additional inferences are

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17 Empirical investigations of these claims of Grosz, Joshi, and Weinstein (1986) suggest they are too strong. In particular, the results of Gordon, Grosz, and Gilliom (1993) suggest that (16d) without the intervening (c) utterance is not as bad as (15c).

18 Sequence (17) is an adaptation of one of Sidner's examples (Sidner 1979).

required to determine that the pronoun does not refer to a member of the current forward-looking centers and to identify the context back to which attention is shifting. Further investigation is required to determine the linguistic cues (e.g., intonation or cue phrases [Grosz and Hirschberg 1992]) and intentional information that are required to enable such shifts while preserving coherence, as well as the effect on inference load.

A third complication arises in the application of Rule 1 in sequences in which the $C_b$ of an utterance is realized but not directly realized in that utterance. This situation typically holds when an utterance directly realizes an entity implicitly focused by an element of the $C_f$ of the previous utterance. For instance, it arises in utterances containing noun phrases that express functional relations (e.g., "the door," "the owner") whose arguments have been directly realized in previous utterances (e.g., a house) as occurs in the sequence,

(19)  a. The house appeared to have been burgled.

    b. The door was ajar.

    c. The furniture was in disarray.

In this segment, the house referred to in (19a) is an element of the $C_f$(19a). This house is the $C_b$(19b); it is realized but not directly realized in (19b). Because the house is the $C_b$, the $C_f$ (19b) includes it as well as the door that is directly realized in the utterance. The $C_b$(19c) is thus again "house." We assume here that the door ranks above the house in $C_f$ (19b). For example, if (19b) is followed by a sentence with 'it' in the subject position, then 'it' is more likely to refer to the door.[19] This is consistent with the ranking of the door ahead of the house in $C_f$ (19b). However, continuity of the house as a potential $C_b$ for (19c) is reflected in the discourse segment being interpreted to be "about" the house and (19c) being interpreted in the same way as (19b) with respect to the house. In Grosz, Joshi, and Weinstein (1986) we did not explore this issue further; the general issue of the roles of functional dependence and implicit focus in centering remain open.[20]

The use of different types of transitions following the rankings in Rule 2 are illustrated by the discourse below.

(20)  a. John has been having a lot of trouble arranging his vacation.

    b. He cannot find anyone to take over his responsibilities. (he = John)
       $C_b$ = John; $C_f$ = {John}

    c. He called up Mike yesterday to work out a plan. (he = John)
       $C_b$ = John; $C_f$ = {John, Mike} (CONTINUE)

    d. Mike has annoyed him a lot recently.
       $C_b$ = John; $C_f$ = {Mike, John} (RETAIN)

    e. He called John at 5 AM on Friday last week. (he = Mike)
       $C_b$ = Mike; $C_f$ = {Mike, John} (SHIFT)

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19 However, it can refer to the house. For example if (b) were followed by "Otherwise from the outside it appeared quite normal. Inside was a different story." A pronoun could also be used in other grammatical roles to refer to the door. We use subject position as the test, because there is no prior sentential context to bias the interpretation.

20 See Section 9 for some recent references related to this issue.

Utterance (20b) establishes John both as the $C_b$ and as the most highly ranked $C_f$. In utterance (20c) John continues as the $C_b$, but in utterance (20d) he is only retained; Mike has become the most highly ranked element of the $C_f$. Finally, in utterance (20e) the backward-looking center shifts to being Mike. Rule 1 is satisfied throughout (20). Rule 1 depends only on the ordering of elements of $C_f$, and not on the notions of retaining and continuation.

## 8. Requisite Properties of Underlying Semantic Theory

Different semantic theories make different commitments with respect to the completeness or definiteness required of an interpretation. Because the information needed to compute a unique interpretation for an utterance is not always available at the time the utterance occurs in the discourse, the ways in which a theory treats partial information affects its computational tractability as the basis for discourse interpretation. It is not merely that utterances themselves contain only partial information, but that it may only be subsequent to an utterance that sufficient information is available for computing a unique interpretation. No matter how rich a model of context one has, it will not be possible to fully constrain the interpretation of an utterance when it occurs. This is especially true for definite noun phrase interpretation. For example, several interpretations are possible for the noun phrase "the Vice-President of the United States," in the utterance

(21)  The Vice-President of the United States is also President of the Senate.

One interpretation, namely the individual who is currently Vice-President, provides the appropriate basis for the interpretation of "he" in the subsequent utterance given in (22):

(22)  Right now, he is the President's key person in negotiations with Congress.

However, a different interpretation, one which retains some descriptive content, provides the appropriate basis for an interpretation of the pronoun "he" in the slightly different subsequent utterance

(23)  Historically, he is the President's key person in negotiations with Congress.

A semantic theory that forces a unique interpretation of utterance (21) will require that a computational theory or system either manage several alternatives simultaneously or provide some mechanism for retracting one choice and trying another later. On the other hand, a theory that allows for a partially specified interpretation must provide for refining that interpretation on the basis of subsequent utterances. Additional utterances may provide further constraints on an interpretation, and sequences of utterances may not be coherent, if they do not allow for a consistent choice of interpretation. For example, the utterance in (24) is perfectly fine after (22), but yields an incoherent sequence after (23).[21]

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21 These examples were first written in 1986 when George Bush was Vice-President. They remain useful for illustrating the original points if the time of original writing is taken into account. As we discuss later, taken as spoken now they illustrate new points.

(24) As Ambassador to China, he handled many tricky negotiations, so he does well in this job.

To summarize, given that one purpose of discourse is to increase the information shared by speaker and hearer, it is not surprising that individual utterances convey only partial information. However, the lack of complete information at the time of processing an utterance means that a unique interpretation cannot be definitely determined. In constructing a computational model, we are then left with three choices: compute all possible interpretations and filter out possibilities as more information is received; choose (on some basis) a most likely interpretation and provide for "backtracking" and computing others later; compute a partial interpretation. We conjecture that this third choice is the appropriate one for noun phrase interpretation.

Centering theory and the centering framework rely on a certain picture of the ways in which utterances function to convey information about the world. One role of a semantic theory is to give substance to such a picture. At the time Grosz, Joshi, and Weinstein (1986) was written, it struck us that situation semantics (Barwise and Perry 1983) provided a particularly convenient setting in which to frame our own theory of discourse phenomena, though our account relied only on general features of this approach and not on details of the theory as then articulated. The two most important features of situation semantics from the standpoint of the theory of discourse interpretation we wished to develop were (1) that it allows for the partial interpretation of utterances as they occur in discourse, and (2) that it provides a framework in which a rich theory of the dependence of interpretation on abstract features of context may be elaborated. There is now a large situation semantics literature that contains many extensions and refinements of the theory to which we refer the interested reader. The original book (Barwise and Perry 1983) may be consulted for an account of the distinction between value-free and value-loaded interpretations used below.

In the discussion and examples in previous sections, the $C_b$ and the elements of $C_f$ have all been the denotations of various noun phrases in an utterance. The actual situation is more complicated even if we ignore for the moment quantifiers and other syntactic complexities (cf. Webber 1978) as well as cases in which the center is functionally dependent on, or otherwise implicitly focused by, an element of the $C_f$ of the previous utterance (cf. Section 7). A singular definite noun phrase may contribute a number of different interpretations to $C_f$. In particular, not only the value-free interpretation, but also various loadings may be contributed.

For example, in the utterance, "The Vice-President of the United States is also President of the Senate," the noun phrase "the Vice-President" contributes both a value-loaded and a value-free interpretation. The value-free interpretation is needed in the sequence (25a–c), whereas the value-loaded interpretation is needed in (26a–c).

(25) a. The Vice-President of the United States is also President of the Senate.

b. Historically, he is the President's key man in negotiations with Congress.

c. He is required to be 35 years old.

(26) a. The Vice-President of the United States is also President of the Senate.

b. Right now, he's the president's key person in negotiations with Congress.

c. As Ambassador to China, he handled many tricky negotiations, so he is well prepared for this job.

The $C_b$(25b) and the $C_b$(26b) are both directly realized by the anaphoric element "he." But $C_b$(25b) is the value-free interpretation of the noun phrase, "the Vice-President" (as in, "The Vice-President of the United States is the President's key man in negotiations with Congress"), whereas $C_b$(26b) is the value-loaded interpretation (as in "the *person who now is* Vice-President of the United States"). That this is so is demonstrated by the fact that (25c) is true in 1994, whereas (26c) is not. Centering accommodates these differences by allowing the noun phrase "the Vice-President of the United States" potentially to contribute both its value-free interpretation and its value-loading at the world type to $C_f$(25a). $C_b$(25b) is then the value-free interpretation, and $C_b$(26b) is the value-loaded one (at the time of the writing of Grosz, Joshi, and Weinstein (1986), George Bush, but now [1995] Al Gore). In each sequence, the (a) utterance underdetermines what element to add to $C_f$. This underdetermination may continue in a subsequent utterance with the pronoun. For example, that would be the case if the introductory adverbials were left off the (b) utterances.

We conjecture that the correct approach to take in these cases is to add the value-free interpretation to $C_f$ and then load it for the interpretation of subsequent utterances if this is necessary. This conjecture derives from a belief that this approach will most effectively limit the inferences required. These loading situations thus constitute a component of the centering constituent of the discourse situation. It remains an open question how long to retain these loading situations, although those corresponding to elements of $C_f$ that are not carried forward (either as the $C_b$ or as $C_f$s of the subsequent utterance) can, obviously, be dropped.

It is possible for an utterance to prefer either a value-free (VF) or value-loaded (VL) interpretation but not force it. For example, the second utterance in the following sequence prefers a VF interpretation but allows for the VL interpretation that is needed in the third utterance.

(27) a. A: The Vice-President of the U.S. is also President of the Senate.

b. B: I thought he played some important role in the House.

c. A: He did, but that was before he was the Vice-President.

In a similar way the second utterance in the following sequence[22] prefers the VL interpretation, but allows for the VF. The third utterance requires the VF interpretation.

(28) a. John thinks that the telephone is a nuisance.

b. He curses it every day.

c. He doesn't realize that it is an invention that changed the world.

In these examples, both value-free and value-loaded interpretations are shown to stem from the same full definite noun phrase.

There appear to be strong constraints on the kinds of transitions that are allowed, however. In particular, if a given utterance forces either the VF or the VL interpretation, then only this interpretation is possible in the immediately subsequent utterance. However, if some utterance only prefers one interpretation (in a given context), but allows the other, then the subsequent utterance may pick up on either one.

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22 Christine Nakatani provided this example, which is far more compelling than the one originally in Grosz, Joshi, and Weinstein (1986).

For example, the sequence,

(29) a. The Vice-President of the United States is also President of the Senate.

b. He's the President's key man in negotiations with Congress.

in which "he" may be interpreted either VF, or VL, may be followed by either (30) or (31):

(30) As Ambassador to China, he handled many tricky negotiations. (VL)

(31) He is required to be at least 35 years old. (VF)

However, if we change (29b) to force the value-loaded interpretation, as in (26), then only the value-loaded interpretation (30) is possible. Similarly, if (29b) is changed to force the value-free interpretation, as in (25b), then only the value-free interpretation (31) is possible.

Speaker intentions may also enter into the determination of which entities are in the $C_f$. The referential uses of descriptions, of which Donnellan (1966) gives examples, demonstrate cases in which the "referential intentions" of the speaker in his use of the description play a role in determining $C_b(U)$. For example, consider the following sequence:

(32) a. Her husband is kind to her.

b. No, he isn't. The man you're referring to isn't her husband.

(33) a. Her husband is kind to her.

b. He is kind to her but he isn't her husband.

In these examples,[23] the speaker uses a description to refer to something other than the semantic denotation of that description, i.e. the unique thing that satisfies the description (if there is one). There are several alternative explanations of such examples, involving various accounts of speaker's intentions, mutual belief, and the like. A complete discussion of these issues is beyond the scope of this paper.

The importance of these cases resides in showing that $C_f(U)$ may include more than one entity that is realized by a single NP in U. In this case, the noun phrase "her husband" contributes two individuals, the husband and the lover, to $C_f(32a)$ and $C_f(33a)$. This can be seen by observing that both discourses seem equally appropriate and that the backward-looking centers of (32b) and (33b) are respectively the husband and the lover, which are realized by their anaphoric elements.

These examples introduce a number of research issues concerning the representation and management of the $C_b$ and $C_f$ discourse entities. The account given here depends on a semantic theory that permits minimal commitment in interpretations. The open question is which constraints on centers are introduced at which points during processing. We must leave this as a topic for future work.

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23 These examples are from Kripke (1977, p. 21).

## 9. Related Work

This theory can be contrasted with two previous research efforts that spurred this work: Sidner's (1979) original work on immediate focusing and pronouns, and Joshi and Weinstein's (1981) subsequent work on centering and inferences.

The centering theory discussed here is quite close to Sidner's original theory, both in attacking local discourse issues and in the general outline of approach. However, it differs in several details. In Sidner's theory, each utterance provides an immediate discourse focus, an actor focus, and a set of potential foci. The discourse and actor foci may coincide, but need not. Her potential foci are roughly analogous to our $C_f$. The $C_b$ for an utterance sometimes coincides with her actor focus and sometimes with her discourse focus. She distinguishes these two to handle various cases of multiple pronouns. However, as we have shown, utterances do not have multiple $C_b$s. Furthermore, utterances can have more than two pronouns, so merely adding a second kind of immediate focus is of limited use. The difference between these two theories can be seen from the following example (from Sidner [1979]):

(34)  a.  I haven't seen Jeff for several days.

b.  Carl thinks he's studying for his exams,

c.  but I think he went to the Cape with Linda.

On Sidner's account, Carl is the actor focus after (34b) and Jeff is the discourse focus. Because the actor focus is preferred as the referent of pronominal expressions, Carl is the leading candidate for the entity referred to by *he* in (34c). It is difficult to rule this case out without invoking fairly special domain-specific rules. On our account, Jeff is the $C_b$ at (34b) and there is no problem. The type of example Sidner was concerned about would occur if utterance (34c) were replaced by "He thinks he studies too much." However, the centering rules would still hold in this case. They provide no constraints on additional pronouns so long as the highest ranked $C_f$ is realized by a pronoun. However, the rules are incomplete; in particular, as given they do not specify which pronoun in a multipronoun utterance refers to the $C_b$. The center management rules are based solely on the $C_b$ and the highest ranked member of the $C_f$. As a result, while there are cases of multiple pronouns for which the theory makes incomplete predictions, having both an actor and a discourse focus will not handle these cases in general.

Joshi and Kuhn (1979) and Joshi and Weinstein (1981) presented a preliminary report on their research regarding the connection between the computational complexity of the inferences required to process a discourse and the coherence of that discourse as assessed by measures that invoke centering phenomena. However, their basic definitions conflate the centers of an utterance with the linguistic expressions that realize those centers. In some of their examples it is unclear whether the shift in center or the particular expression used to realize the center is responsible for differences in coherence and inference load. Our present work has clarified these differences while maintaining Joshi and Weinstein's basic focus on the interaction between inference load and center management.

Since Grosz, Joshi, and Weinstein (1986) was first circulated a number of researchers have tested and developed aspects of the theory presented here.[24] This

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24 Our listing in this section is based on the best information available to us. It is quite possible that we have missed some references. We will be grateful if readers could send us missing references.

follow-on research can be roughly grouped in a few main areas:

- Cross-linguistic work on centering:[25] (German, Hebrew, Italian, Japanese, Korean, and Turkish): Di Eugenio (1990); Hoffman and Turan (1993); Kameyama (1985, 1986, 1988); Rambow (1993); Walker, Iida, and Cote (1990, 1994); Yongkyoon (1991); Ziv and Grosz (1994).

- Centering algorithms: Baldwin (1993); Brennan, Friedman, and Pollard (1987); Kehler (1993); Walker (1989); Walker, Iida, and Cote (1994).

- Empirical and psycholinguistic evaluation of centering predictions: Brennan (1995); Gordon and Chan (in press); Gordon, Grosz, and Gilliom (1993); Gordon and Scearce (1995); Hudson-D'Zmura (1988); Hudson, Tanenhaus, and Dell (1986); Walker (1989).

- Centering and linguistic realizations:[26] Cote (1992, 1993); Hurewitz and Linson (1993); Kameyama (1993); Nakatani (1993); Passonneau (in press, 1991); Prince (1994); Prince and Walker (1995); Suri and McCoy (1993); Turan (1995); Walker (1989).

- Centering, dialogue, and global discourse structure: Brennan (1995); Hurewitz and Linson (1993); Roberts (1993); Sparck Jones (1993); Walker (1993); Walker and Whittaker (1990).

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26 Kameyama's dissertation research (Kameyama 1985) was carried out contemporaneously with the extensions from our 1983 paper to Grosz, Joshi, and Weinstein (1986). This work was the first to establish a correspondence between pronouns in English and zero anaphors in Japanese with respect to interactions with centering.

26 Turan's recent work (Turan 1995) is about the realization of subjects in Turkish and not centers in particular. She has studied the distribution of full NP, overt pronoun, and zero pronoun subjects in Turkish and shows that speakers choose one over the other when all are allowed by the grammar in accordance with the salience of the discourse entity represented following a centering theory account of salience.

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