Cross-speaker anaphora in dynamic semantics

Jae-Il Yeom*
Hongik University

Jae-Il Yeom. 2010. Cross-speaker anaphora in dynamic semantics. *Language and Information 14.2*, 103–129. In this paper, I show that anaphora across speakers shows both dynamic and static sides. To capture them all formally, I will adopt semantics based on the assumption that variables range over individual concepts that connect epistemic alternatives. As information increases, a variable can take a different range of possible individual concepts. This is captured by the notion of virtual individual (= *vi*), a set of individual concepts which are indistinguishable in an information state. The use of a pronoun involves two information states, one for the antecedent, which is always part of the common ground, and the other for the pronoun. Information increase changes *vi*s for variables in the common ground. A pronoun can be used felicitously if there is a unique virtual individual in the information state for the antecedent which does not split in two or more distinctive virtual individuals in the information state for the pronoun. The felicity condition for cross-speaker anaphora can be satisfied in declaratives involving modality, interrogatives and imperatives in a rather less demanding way, because in these cases the utterance does not necessarily require non-trivial personal information for proper use of a pronoun. (**Hongik University**)

Key words: anaphora, pronoun, dialog, cross-speaker, individual concept, virtual individual

1. Introduction

The term 'cross-speaker anaphora' is used first by Francez and Berg (1994) to indicate reference by one conversational participant to a discourse entity introduced by another. It has a lot in common with anaphora across attitude contexts (Dekker & van Rooy 1998, van Rooy 2000, etc.), but there are some aspects which are only observed in dialogs. Francez and Berg (1994), Groenendijk, Stokhof and Veltman

* This work was supported by 2007 Hongik University Research Fund. I thank three anonymous reviewers for their comments and their time spent in reading this paper. All errors are mine. Address: Hongik University, Dept. of English Language and Literature, 72-1 Sangsu-dong, Mapo-gu, Seoul 121-791, KOREA. E-mail: jiyeom@{hongik.ac.kr/gmail.com}

(1997), Dekker (1997), Poesio (1998), Groenendijk and Stokhof (2000), etc. discussed aspects of anaphora in dialogs. Previous analyses are not adequate for explaining some properties of cross-speaker anaphora. In this paper I propose a new analysis which can capture the aspects of anaphora in dialogs, To do this, I need to deal with the issues of what a pronoun refers to and when a pronoun is used felicitously in dynamic setting.

In dealing with cross-speaker anaphora, there are some aspects which should be captured but are not adequately dealt with by previous analyses. First, in traditional dynamic semantics, a pronoun has been taken to refer to the same INDIVIDUAL as the referent of its antecedent determined by an assignment function. However, this cannot be maintained when more than one information state is involved. This is clear when an example like (1) considered. Mary is assumed to know John and Bill. She is looking at John from a distance and mistakes him to be Bill:

(1) John is walking in the park, but Mary thinks he is Bill.

If the pronoun in this example referred to the same individual as its antecedent, the sentence would mean that Mary believes John is Bill. But Mary does not believe so.[1] This shows that what we are dealing with is not an individual. The variable from a pronoun has to take as its value something which can denote John in a context and denote Bill in another context. This requires the notion of **individual concept**, which is a function from a set of possible worlds to a set of individuals.

Second, there is no previous account which deals with the dynamic aspect of anaphora, as far as I know. Reference of a pronoun shows dynamic and static features. Suppose that there are two murder cases involving Smith and Jones. B(ob) knows that one and the same person killed both, while A(my) believes that two murders are not related. In this context, the examples in (2) show that the way that information is conveyed by utterances is important to determine the referent of a pronoun.

(2) a. A: Someone murdered Smith.
B: He also killed Jones.
A: No, he didn't.

b. B: Someone murdered Smith. He also killed Jones.
A: ??No, he didn't.

In neither of these two dialogs do A or B get any new information except for getting to know what the other party believes. Yet these two examples show that there is *asymmetry* in anaphora across speakers. In (2a), A introduces someone who murdered Smith. B adds some information about that individual. A does not accept what B adds, but there is no problem in A's using a pronoun to refer to the murderer of Smith. In (2b), the sequence of the sentences uttered is the same, but the first

[1] We can say a similar thing in dealing with Quine's *double vision* case. Ralph sees a man in a brown hat and believes him to be a spy, and later he sees a man with gray hair and thinks him not to be a spy. It turns out that the two men are the same person named Ortcutt. In this case, Ralph does not believe that one and the same person is a spy and is not a spy at the same time.

two sentences are uttered by the same speaker. B first introduces the murderer of Smith and adds the information that he also murdered Jones. In this situation, the murderer of Smith and the murderer of Jones are merged and A cannot refer to the murderer of Smith, separately from the murderer of Jones. This shows that what a pronoun can refer to depends on the way information increases in the common ground and that the felicity of the use of a pronoun depends on what the speaker already knows/believes, together with the way information increases. Information change is a dynamic side of information, while what the speaker already knows is a static side of information. The use of a pronoun is affected by both.

In (2), the properties attributed to an individual introduced are important in determining the felicity of the use of a pronoun.[2] However, there are cases where properties attributed to an individual do not seem important, as in (3).

(3) A: A man jumped off the bridge yesterday.
B: He didn't jump, he was pushed.

(3′) A: $\exists$x[man(x) $\wedge$ jump-off(x)] (ϕ_1)
B: $\neg$jumped-off(x); $\exists y$[pushed(y,x)] (ϕ_2; ϕ_3)

In B's utterance the properties A attributed to the man who jumped off are denied even though the pronoun refers to him. This does not mean that the relation of anaphora is already established in B's personal (= not shared with other conversatioal participants) information state, independently of the discourse.[3] Still, without some properties attributed to the man by A, B would not be able to identify the man with the one in his own personal information state. This shows that properties attributed to an individual always play a role in allowing the use of a pronoun in a dialog.

This is compared with a case of intentional identity, where a pronoun in one belief context corefers with the antecedent in a different belief context, which was first discussed in Geach (1967):

(4) Hob believes a witch has blighted Bob mare, and Nob thinks she killed Cob's sow.

This is not a dialog and one difference is that the coreference is, if ever, based on some properties which are not mentioned in the actual statement. In this respect, the reference of a pronoun is statically identified with that of its antecedent. This is different from cross-speaker anaphora illustrated in dialog situations like (2) or (3).

Third, in questions and commands, no matching seems to be required between individuals in the common ground and those in the personal information states. In

[2] What is taken to be an individual in an information state is called a subject. A more formal definition will be given below.

[3] When we say that a statement updates an information state, the information state is the common ground. By a "personal" information state, I mean an information state which is not in the common ground. For a more precise relation between them is discussed in Subsection 2.2.

the following discourse, it seems that the use of a pronoun does not require other information than what is given in the dialog.[4]

(5) A: Someone killed Smith.
B: Does he live in Chicago?

(6) A: There is an engine at Avon.
B: Send it to Bath.

In these examples, it is not required for B to have any individual in his own personal information state separately from the one introduced by A. This shows that in these cases no correspondence relation is necessary between an individual in the common ground and an individual in the speaker's own personal information state. This means that in utterances like questions and commands, anaphora does not have to be established in the speaker's personal information states. In this paper I will discuss why anaphora must be established in the speaker's own personal information state in ordinary statements and it does not have to be in other utterances. I will also discuss how anaphora is established when it is necessary.

This paper is organized in this order. First, the notions of individual concept and virtual individual are introduced to connect two individuals in different information states. And types of utterances are discussed with respect to what informations are involved in using pronouns. In Section 3, the felicity condition for pronouns in ordinary statements is given using the notion of correspondence between unique virtual individuals connecting two different information states. The felicity condition behaves like a presupposition from the use of a pronoun. I will discuss how this information is reflected in the common ground. Finally, it is discussed how the felicity condition is satisfied in questions and commands.

2. Structured Information states and individual concepts

2.1 Individual concepts as connectors across information states

In (1), there is a correspondence relation between John in the main context and Bill in Mary's belief context. That is, the property of walking in the park is attributed to John in the main context and to Bill in Mary's belief context. In (3), A and B attribute different properties to the same individual. Nevertheless there should be some non-arbitrary connector which imposes a correspondence relation between two individuals across speakers. We need a semantic entity which can denote different individuals in different context. One such thing is an individual concept.

Saarinen (1978) first tried to account for anaphora across information states by assuming that variables range over *individual concepts.* Edelberg (1992), however, claimed that with the notion of *individual concept* we could not account for the *asymmetry problem* observed in the example below. Assume the same situation for example (2). In this situation, (7) is true, and (8) false (Edelberg 1995):

(7) Amy believes that someone murdered Smith, and Bob believes *he* murdered Jones.

[4] The last two examples are from Clark and Schaefer (1989). They pointed out that cross-speaker anaphora is relatively easy in uttering an imperative or interrogative.

(8) Bob believes that someone murdered Jones, and Amy believes *he* murdered Smith.

However, Edelberg claimed that (8) could be true with respect to the individual concept *the murderer of Smith*. Based on this problem, Edelberg refutes the idea that variables range over individual concepts.

The problem with Saarinen's analysis, however, does not lie in the use of the notion of individual concept, but in the fact that Saarinen's analysis is not dynamic: her discussion is based on the notion of truth. In anaphora we need to capture how a possible referent of a pronoun changes as information increases. Relevant individual concepts must be restricted by information increase. In (7), the first statement of Amy's belief invokes the individual concept *the murderer of Smith*. In Bob's belief state, *the murderer of Smith* murdered Jones too, which (7) asserts. In (8), the statement of Bob's belief invokes *the murderer of Jones*, not *the murderer of Smith*, as Edelberg (1995) supposes. And Amy does not believe *the murderer of Jones* murdered Smith. This is why (8) is taken to be false. To account for the differences, we have to assume that the choice of an individual concept relevant is restricted dynamically by information change. If the dynamic side of anaphora is considered, the notion of individual concept is still viable.

Individual concepts are defined globally so that they are used to capture correspondence relations between individuals across possible worlds. However, the notion of individual concept itself may not be adequate to capture the idea of an individual in the way that an agent takes it to be in his or her information state. Suppose that A and B are looking out the window late at night, and that A notices a woman sitting at a bench in the park.

(9) A: A woman is sitting at a bench over there this late.
B: She lives next door.

In the first statement, A introduces a woman sitting at a bench in the common ground, but the variable from *a woman* may take an infinite number of individual concepts, including some individual concepts like *the woman sitting at a bench (at a particular time) and living next door* and *the woman sitting at a bench (at a particular time) and living across the street*. B's statement does not eliminate assignments which assign to the variable individual concepts like the latter. At the time that A's statement is made, each of the two individual concepts does not reflect the amount of information A and B share: each keeps more than the information they share at the moment. However, the existence of the two in the same common ground conveys the information that it is not yet known whether the woman lives next door or across the street. The individual as B (and A in the common ground) conceive(s) after A's statement is more like *the woman sitting at a bench (at a particular time)*. But the individual concepts which convey more information are also in the common ground so that they can be selected as a relevant individual concept later when information increases.

To deal with anaphora across speakers or across information states formally, we need to make some concrete assumptions about a model and interpretation rules based on the notion of individual concept. Let the model be $M = \langle W, D, V, F \rangle$,

where F is an interpretation function of constants in the language, and W, D and V are sets of possible worlds, individuals and variables respectively. An individual concept is defined as follows:

> Given a model $M = \langle W, D, V, F \rangle$,
> a set of individual concepts $IC = \{ic \in D^U \mid U \subseteq W\}$

Given a set of possible worlds W and a set of individuals D in the model, an individual concept is defined as a (partial) function from a subset of W into D: for some possible worlds, there can be no individual assigned.[5] Here a function is considered to be a set of pairs of a possible world and an individual.

There must be some remarks about individual concepts. In an individual concept ic, each individual in $ic(w)$ is taken to be an *epistemic counterpart* of an individual in $ic(w')$ in another possible world w' in $dom(ic)$. I suppose that the individuals are characterized by some properties.[6] Second, an individual concept is not defined with respect to a local context, but it is defined globally. If a set of properties is determined, an individual concept must include all pairs of a possible world and a unique individual that satisfies the properties, if there is any, in every possible world. By defining individual concepts globally, we can use them as a means of connecting different individuals across different information states.

There is some ordering relation between individual concepts. An individual concept *the individual who is smart and attractive* conveys more information than *the individual who is smart.* For any two individual concepts, ic_i and ic_j, ic_i conveys more information than ic_j if the following condition is met:

> An individual concept ic_i is at least as much informative as an individual concept ic_j iff for every possible world w in $dom(ic_i)$: $ic_i(w) = ic_j(w)$.

As information increases, a more specific and more informative individual concept is selected for a variable. To capture the dynamic side of information, we have to

[5] Aloni (1997) claims that a quantifier quantifies over a set of individual concepts, and that the set is determined from a certain perspective. Once a perspective determines a set of individual concepts, a pronoun which takes the quantifier as its antecedent comes to get one individual concept in the set as its value. Such a set of individual concepts is called a *conceptual cover.* This will restrict the possible values of the variable further. In a conceptual cover each individual d is identified by at least one concept in each world (existence), but in no world is an individual counted more than once (uniqueness). I do not think a notion like conceptual cover is not necessary here. Quantification needs a domain which is determined in a context, so it is necessary to get a full set of individual concepts from a perspective. In this paper, we are more concerned with anaphora between non-quantificational NPs, and between two different information states. I think information change leads to context change. And cross-speaker anaphora involves a speaker's personal information state, which is independent of the current context. In this respect, we do not need to assume that there is a perspective given in the context. In most cases, more than one perspective is involved.

[6] Here I need to assume that each individual concept is definite in the sense that an individual concept is associated with a set of properties and that it is defined in a possible world only when there is only one individual that has the set of properties, but this make the explanation complex. For example, informativeness of an individual concept defined below must be more complex. I will not go out of the way to deal with such cases because the discussion below does not need such complexity: the least informative individual concept is already definite and any other individual concept is too.

assume that if an assignment in an information state assigns an individual concept to a variable, there are other assignments which assign more informative individual concepts to the same variable.

Since a variable ranges over individual concepts, a (variable) assignment is a function from a set of variables to a set of individual concepts.

> An assignment g is a member of $G = \{g \in IC^X \mid X \subseteq V\}$, where IC is a set of individual concepts given in the model and V a set of variables.

As I said, an individual concept is defined globally with respect to a subset of W. This allows us to capture identity of individuals between different possible worlds.

As in the standard theory of dynamic semantics, an information state is defined as a set of world-assignment pairs.[7]

> A set of information states $S = \{s \subseteq U \times E \mid U \subseteq W,$
> $E \subseteq \{g \in G \mid X \subseteq V, dom(g) = X\}\ \}$

Here assignments in an information state have the same domain.

Now I will briefly explain how statements are interpreted. An information state s is updated with a sentence as follows:

> $s[P(x)] = \{\langle w, g\rangle \in s \mid g(x)(w) \in F(P)(w)\}$, if x is in the domain of g;
> otherwise undefined.
> $s[\neg\phi] = \{\langle w, g\rangle \in s \mid$ there is no g^+ such that $\langle w, g^+\rangle \in s[\phi]\}$
> $(g^+ = g \cup f$, where $f \in IC^X$ such that $X \subseteq V$ and $X \cap dom(g) = \emptyset.)$
> $s[\phi \wedge \psi] = s[\phi][\psi]$
> $s[\exists x\phi] = \{\langle w, g^{+\{x\}}\rangle \mid \langle w, g\rangle \in s\}[\phi]$
> $(g^{+\{x\}} = \{g \cup \{\langle x, ic\rangle\} \mid ic \in IC\})$

When an information state s is updated with a simplex formula $P(x)$, x is in the domain of every assignment in the information state. $\langle w, g\rangle$ in the information state is not excluded if $g(x)(w)$ is an individual which has property P in w. The negation of a sentence $\neg\phi$ excludes a pair of a world and an assignment if the pair can be extended to support the affirmative counterpart ϕ. The conjunction of two sentences is just like two separate sequential sentences. The existential quantifier extends the domain of the assignments in the information state.

In the paper the main concern is how a variable is introduced by one speaker in the common ground and how a pronoun is used felicitously by another speaker to refer to the variable. To see how, it is necessary to show how a formula with the existential quantifier is interpreted and what the resulting information state is like. Assuming that the current information state is s, a formula $\exists x P(x)$ is interpreted as follows:

$$s[\exists x P(x)] = \{\langle w, g^{+\{x\}}\rangle \mid \langle w, g\rangle \in s,\ g^{+\{x\}}(x)(w) \in F(P)(w)\} = s'$$

In s', the individual concepts assigned to a variable x by g can be assumed to be one of the following:

[7] To deal with commands, this must be modified slightly. See subsection 3.4.2.

	w_1	w_2	w_3	w_4	w_5
ic_1		a			
ic_2		[a]	d	c	
ic_3	a		[b]		e
ic_4	a	c	b	[d]	
			s'		

Suppose that $s' = \{\langle w_2, g_2\rangle, \langle w_3, g_3\rangle, \langle w_4, g_4\rangle\}$, where $g_2(x) = ic_2$, $g_3(x) = ic_3$ and $g_4(x) = ic_4$. Thus the statement is true w.r.t. a in w_2, b in w_3 and d in w_4. In this context, ic_2, ic_3 or ic_4 cannot be referred to from a different information state. Furthermore, each of the ic's does not reflect the information conveyed by the statement $\exists x P(x)$. In ic_2, a in w_2 has the property P, but d in w_3 or c in w_4 does not. Similarly, in ic_4, c in w_2 or b in w_3 does not have the property P. If an ic is to reflect the information in an information state, every individual in the ic must have the property attributed to the corresponding variable in the domain of the information state.

This can be illustrated in the following:

(10) a. ??John believes that he saw only one monster, but it was just an illusion.

b. John believes that he saw a certain monster, but it was just an illusion.

In (10a), there is only one monster in each of John's belief worlds, so the uniqueness condition is met with respect to each world in John's belief context. But it is not referred to from the main context. This seems related to the one-to-many relationship between a possible world in the main context and John's belief worlds (plus multiple individual concepts relevant to his belief). In (10b), on the other hand, *a certain monster* can be referred to by a pronoun from the main context despite the one-to-many relationship between a possible world in the main context and John's belief worlds from it. This can be explained by the existence of a unique individual concept which is fully defined with respect to John's belief context. This is illustrated as follows:

	w_1	w_2	w_3	w_4	w_5
$g_1(x) = \text{ic}_1$	a		d		
$g_2(x) = \text{ic}_2$		[b]	a		
$g_3(x) = \text{ic}_3$			[c]	e	
$g_4(x) = \text{ic}_4$			f	[d]	
$g_5(x) = \text{ic}_5$		a			e
		John's BS			

	w_1	w_2	w_3	w_4	w_5
$g_6(x) = \text{ic}_6$			[c]	f	
$g_7(x) = \text{ic}_7$	a	[b]	[c]	[d]	e
$g_8(x) = \text{ic}_8$		[b]	[c]		
		John's BS			

Here the monsters John saw in his belief context are boxed. In the first table, there is only one individual in each world in John's belief context who is the monster John saw, but each individual belongs to a different individual concept. This is the result we get from the interpretation of (10a). The second table is something we can get from the interpretation of (10b), which requires an individual concept like $g_7(x)$. The three (boxed) individuals in John's belief state from $g_7(x)$ all have the property of being the unique monster John saw. I will call such an individual concept a **specific individual concept** (= sic) in John's belief state. When a pronoun is used to refer to an antecedent, it takes a specific individual concept or individual concepts indistinguishable with it. This idea will be elaborated below.

There may be multiple individual concepts assigned to the variable x like $g_6(x)$ and $g_8(x)$, but they are indistinguishable with $g_7(x)$ in John's belief context. The three individual concepts look like the same individual to John. Such a set of individual concepts is called a **virtual individual**. The use of a pronoun does not simply imply the uniqueness of an individual, but the uniqueness of a virtual individual which can be referred to by both the antecedent and the pronoun.

In an agent α's information state s_α, a specific individual concept and a virtual individual are defined as follows:

> An individual concept ic is a **specific individual concept** (= **sic**) for a variable x in an information state s iff there is an assignment g such that $x \in dom(g)$ and for every possible world $w \in dom(s)$, $\langle w, g\rangle \in s$, and $g(x) = ic$.
>
> A **virtual individual** (= **vi**) is a member of $[x]_{s_\alpha}$, where
> $[x]_{s_\alpha} = \{\{g(x) \in IC |\ \langle w, g\rangle \in s_\alpha,\ g(x)$ is indistinguishable to $g'(x)$ in $s_\alpha\} |$
> $g'(x)$ is a sic in $s_\alpha\}$
>
> An individual concept ic_i is **indistinguishable** with ic_j in s_α iff $dom(ic_i) \cap dom(ic_j) \cap dom(s_\alpha)$ is $dom(ic_i) \cap dom(s_\alpha)$(or $dom(ic_j) \cap dom(s_\alpha)$), and for every w in $dom(ic_i) \cap dom(s_\alpha)$(or $dom(ic_j) \cap dom(s_\alpha)$), $ic_i(w) = ic_j(w)$.

A specific individual concept sic in an information state s is defined as an individual concept which is fully defined in s and for every possible world w in $dom(s)$, $ic(w)$ is compatible with the information in s. Then the assignment g which assigns the individual concept to the variable x must be paired with every possible world w in $dom(s)$. A virtual individual is a set of individual concepts which are indistinguishable with a specific individual concept. If there is more than one specific individual concept which is distinguishable in an information state, $[x]_s$ has more than one virtual individual. In the example above, ic_7 is a specific individual concept in the information state. $\{ic_7, ic_8\}$ constitutes a virtual individual. The notion of a virtual individual in an information state allows us to capture two aspects of anaphora. Since it is defined as a set of individual concepts which are globally defined, it can connect two *vi*'s in two different information states. On the other hand, it is defined with respect to an information state, so it changes as information increases in that information state. This allows us to select an appropriate *vi* at an information state. For a variable x, $[x]_{s_\alpha}$ is a set of virtual individuals, and each virtual individual is taken to be an individual to an agent α in an information state

s_α. If $[x]_{s_\alpha}$ has more than one virtual individual, a speaker does not know what the variable x is about, and he or she cannot refer to it.

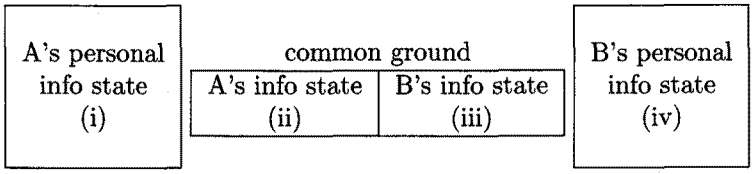
The notion of a virtual individual can be compared with the notion of subject. In previous analyses, the notion of a subject has been proposed to capture an individual as conceived by an agent. This is defined in two different ways. One is to define it as a set of pairs of a possible world and an individual, which is proposed by Dekker (1993). The other way, proposed by Janssen (1986), is to define it as a set of pairs of a possibility and an individual, where a possibility is a pair of a possible world and an assignment which assigns an individual to a variable. Following Dekker (1993), a subject can be defined as follows:

$$\text{A subject }]x[_{s_\alpha} = \{\langle w, d\rangle |\ \langle w, g\rangle \in s_\alpha,\ d = g(x)(w)\}$$

The notion of a subject is not adequate for dealing with anaphora. First, there is no adequate device to connect two different subjects in two different information states. Second a pronoun does not seem to refer to a subject because a subject may have more than one individual in one possible world which has the properties attributed to the variable. In the notion of a subject, there is no independent way of distinguishing one individual from another when a variable is assigned more than one individual. As will be clear in the discussion below, a pronoun seems to be used when it refers to a unique individual for a variable that has a set of properties given. Third, a variable can take a particular and specific individual or an arbitrary individual as its value, but in the notion of a subject this distinction cannot be incorporated. In the notion of a virtual individual, an individual concept can be used to distinguish one individual from another for the same variable, depending on which individual concept each individual belongs to.

2.2 Information states relevant for anaphora

In the standard dynamic semantics, a common ground is assumed to have a single information state. To deal with conversations, however, it is important who makes what statement, as shown in (2-3). This motivates multiple information states in a common ground. In addition, we have seen that in the use of a pronoun in a statement, the speaker's personal information state is involved as well. So in order to account for the use of a pronoun, we need the following four information states, assuming that there are two conversational participants in a conversation:



$$\text{common ground} = \langle (ii)s_A\{(i)s_A^p\}, (iii)s_B\{(iv)s_B^p\}\rangle$$

The four information states are labeled as (i) $\sim$ (iv). Here A's and B's personal information states include the information in (ii) and in (iii) respectively, but they are not directly involved when the common ground is updated with a statement. On the other hand, when each speaker makes a statement, it must be true in his/her

personal information state. And the statement may include a pronoun. To explain how a pronoun is appropriately used, we need to know what information states are involved.

In (2), A introduces an individual in (ii), which is also introduced in (iii) because B accepts what A says. B uses a pronoun by identifying the individual which is introduced in (ii) and accepted in (iii) with an individual in (iv). In (3), A introduces an individual in (ii), too. B does not accept completely what A says, but B accepts the individual introduced by A and identifies it with an individual in his personal information state. This has the effect of presupposing the existence of the individual and some attributions to it but rejects the rest of A's attributions. The presupposition introduces an individual in (iii) without accepting what A says completely. This shows that B's use of a pronoun in an ordinary statement involves the information states of (ii), (iii) and (iv). The information state (iii) is not definitely determined because it is impossible to know for sure how much of what A says is accepted when a pronoun is used. If B makes a statement and A uses a pronoun, the condition for an appropriate use of it involves (i), (ii) and (iii).

Since a common ground consists of more than one information state, it must be defined how a common ground is updated with a statement. With two speakers A and B in the context, we can assume that a common ground is like $\langle s_A\{s_A^p\}, s_B\{s_B^p\}\rangle$, where s_A and s_B are A's and B's information states and s_A^p and s_B^p are A's and B's personal information states respectively.[8] A's and B's personal information states carry all information in s_A and s_B in them. Suppose that $cg = \langle s_A, s_B\rangle$, ignoring the personal information states. When a statement ϕ is made at a context $c = \langle A, B, t\rangle$, where A is the speaker, B the addressee and t the utterance time, a common ground is updated in one of the following two ways, depending on whether the hearer accepts the utterance:

(i) $\langle s_A, s_B\rangle[\phi]^c = \langle s_A[\phi], s_B\rangle$
(ii) $\langle s_A, s_B\rangle[\phi]^c = \langle s_A[\phi], s_B[\phi]\rangle$

If B does not accept it, the statement updates only A's information state. This is what happens in (3). But if B accepts it, then the update goes further and B's information state becomes $s_B[\phi]$. Utterances like questions and commands update a common ground in different ways than statements. This will be discussed in section 3.4.

When B does not accept an utterance in which an individual is introduced, he cannot use a pronoun in his statement to refer to the individual, as shown in (11).

(11) A: Last night a man tried to break in my house.
B: ??No, *he* didn't. It was me.
A: Was it you?

Even when B does not accept the existence of an individual, A can use a pronoun to refer to the individual she introduced herself. This is shown in (12).

[8] As Clark and Schaefer (1989) pointed out, utterances in a conversation do not immediately become part of the shared information among the conversational participants. Even before an utterance becomes part of the shared information, it may introduce a variable or discourse referent. This motivates separate information states for conversational participants.

(12) A: Last night a man tried to break in my house.
B: What time was it?
A: It was around two in the morning.
B: Then it was me.
A: No. I saw *him* run away when the alarm rang.
B: You probably saw my friend.

This shows two things. First, the separation of A's and B's information states is necessary in the common ground. Second, A can refer to the individual she introduced in the common ground regardless of whether B accepts it. So when A uses a pronoun to refer to the individual she introduced herself, only (i) and (ii) are involved.

We have seen that questions and commands are different from ordinary statements. But the user of a pronoun at least has to assume the existence of the individual introduced by another speaker, whether temporarily or permanently. (13) is an example of a question.

(13) A: Last night a man tried to break in my house.
B: Did you see *him*?
A: No, but the security alarm rang and I had to get up at two in the morning.
B: Then it was me. I pushed the wrong button and didn't know how to stop it.

In some sense B temporarily accepts what A says when he uses the pronoun. Thus the information states involved in using a pronoun in a question are (ii) and (iii). Information state (iv) does not have to be involved because B can use a pronoun even when he does not have any information about the individual. We can say the same thing about commands. In these respects questions and commands are different from statements. Therefore to deal with anaphora in a dialog and its different behaviors in different utterances, we need the information states of all the conversational participants in the common ground and their personal information states. And the set of information states necessary to explain anaphora depends on who makes what utterances. Under the assumption that A introduces an individual in (ii), this is summarized as follows:

UTTERANCES	INFO STATES INVOLVED
B's statements	(ii), (iv) including (iii)
A's any utterances	(i), (ii)
B's questions, commands	(ii), (iii)

(Assumption: A introduced an antecedent.)

3. Felicity condition for pronouns

3.1 Statements without the possibility operator

Different utterances involve different information states in licensing uses of pronouns. First, we can give the felicity condition which is required to be satisfied in

using a pronoun in a statement without modality in order to refer back to an antecedent introduced by another speaker. As I have shown, the selection of relevant individual concepts is restricted by the common ground. When A introduces an individual with some attributions to it in information state (ii), it cannot be directly the antecedent of a pronoun used by B. It is because an individual A believes to have some attributions could correspond to an individual B believes to have different or opposite attributions. So if B is to refer to an individual A introduces in (ii) in the common ground, he must introduce it in (iii) by accepting all or part of what A says about the individual.

When B accepts all of what A says, he can refer to the individual by being certain that there is a unique *vi* relevant which connects the three information states (ii), (iii) and (iv). That is, what A says about the individual is sufficient to select a unique *vi* based on his personal information state.[9] But what is more important, the uniqueness is ascertained in B's information state and B must accept the existence of the corresponding individual in his own information state of the common ground. Considering these facts, the felicity condition for a proper use of a pronoun can be specified as follows:

> **Felicity Condition on Cross-Speaker Anaphora:**
> A pronoun which is used by a speaker α to refer to an antecedent in β's information state of the common ground is licensed if the unique *vi* in $[x]_{s_\beta}$ corresponds to the unique *vi* in s^p_α including s_α.
>
> A unique *vi* in $[x]_{s_\beta}$ corresponds to a unique *vi* in $[x]_{s^p_\alpha}$ iff there is a common *sic* such that $sic \in \downarrow [x]_{s_\beta} \cap \downarrow [x]_{s^p_\alpha}$.
>
> ($\downarrow \{\gamma\} = \gamma$; undefined if $\{\gamma\}$ has more than one member.)

When β introduces an antecedent in the common ground, it first determines individual concepts which reflect the current information state. They are partitioned into a set of *vi*'s. In order for α to use a pronoun to refer to the antecedent, first the individual concepts must be indistinguishable with a specific *ic* in s_β. It means that there is a unique *vi* in $[x]_{s_\beta}$. Second, there must be a unique *vi* in $[x]_{s^p_\alpha}$ too. Third, the two unique *vi*'s must be taken to be the same. This is ensured if there

[9] This may be related to the condition of uniqueness as Kadmon (1990) claims. When a pronoun refers to an antecedent by resorting to an individual concept, we normally assume that there is a unique individual in each possible world that has the properties attributed to the antecedent. However, Dekker (2002) gives an example where it might be thought that a pronoun behaves like a bound variable. Suppose that Wilburt and Norbert visited Liz's office and inquired after the secretary's office, and that only Wilburt was wearing pink pumps. Liz lost her keys at his office and believes that one of the two took the keys. She is wondering if the one who got the keys left them with Zil. In this situation the discourse goes like the following:

i. Liz: Yesterday, a HiWi ran into my office who inquired after the secretary's office.
Zil: Was he wearing pink pumps?
Liz: Ehmm, I don't know. If it was Wilburt he was, if it was Norbert, he was not.

In Liz's second statement, *he* might be thought to be a bound variable ranging over Wilburt and Norbert, but actually it refers to the unique *vi the HiWi who ran into Liz's office and asked where the secretary's office is*. It may be Wilburt or Norbert, but it is a matter of epistemic indeterminacy from a different perspective.

is a common specific *vi* for the variable x both in s_β and in s^p_α. If there is more than one *vi* in $[x]_{s^p_\alpha}$, then α will wonder who β is talking about.

The felicity condition of a pronoun allows us to explain the observations in (2). (2) is a case of asymmetry in anaphora across speakers. The order of sentences uttered affects the possibility of anaphora.

(2) a. A: Someone$_x$ murdered Smith. ($= \exists x$[murdered-Smith(x)] $= \phi_1$)
B: He$_x$ also killed Jones. ($=$ killed-Jones$(x) = \phi_2$)
A: No, he$_x$ didn't. ($= \neg$killed-Jones $= \phi_3$)

b. B: Someone$_x$ murdered Smith. He$_x$ also killed Jones.
A: ??No, he$_x$ didn't.

Suppose that the common ground begins with $\langle s_A\{s^p_A\}, s_B\{s^p_B\}\rangle$. In (2a), if the first sentence ϕ_1 is interpreted and it is accepted by B, the common ground becomes $\langle s'_A, s'_B\rangle$ excluding individual concepts like ic_D, assuming that e, d and c did not kill Smith in w_2, w_4 and w_5 respectively, and we can get a new *vi* $\downarrow [x]_{s'_{A/B}} = \{ic_S, ic_{SJ}\}$.

$s_{A/B}[\exists x$[murdered-Smith(x)] $= \{\langle w, g^{+\{x\}}\rangle |\ \langle w, g\rangle \in s,\ g^{+\{x\}}(x)(w)$ murdered Smith $\} = s'_{A/B}$

	w_1	w_2	w_3	w_4	w_5	$g(x) \in s'_{A/B}$	$g(x) \in s''_B$	$g(x) \in s''_A$
ic_D		e		d	c			
ic_S	e	d	f	b		√	√	√
ic_J	d	a	f	b			√	√
ic_{SJ}			f	b			√	
	s^p_A			s^p_B				
	$s_{A/B}$							
	$s'_{A/B}$							
	s''_A		s''_B					

ic_D = *the murderer of David*
ic_S = *the murderer of Smith*
ic_J = *the murderer of Jones*
ic_{SJ} = *the murderer of Smith and Jones*

$\langle w_3, g(x)\rangle$ and $\langle w_4, g(x)\rangle$ such that $g(x) = ic_J$ are in $s'_{A/B}$, but they are not in the *vi* because it has different individuals from the specific *ic* ic_S in w_1 and w_2: *d* and *a* did not kill Smith in w_1 and w_2 respectively. ic_{SJ} is in the *vi* because all individuals given by it in the domain of $s'_{A/B}$ murdered Smith. But it is not a *sic* because it is not completely defined in the domain of $s'_{A/B}$. The murderer of Smith

may also turn out to be the murderer of Jones later. Then ic_J will be in the *vi*. But at the moment ic_S is the specific individual concept in $s'_{A/B}$.

Now the second sentence ϕ_2 is a factual statement based on B's own personal information state. B finds that a unique *vi* ($= \{\{ic_S, ic_J, ic_{SJ}\}\}$) corresponds to the unique *vi* in $[x]_{s'_A}$. ic_S belongs to the unique *vi* in s'_A and that in s^p_B. This licenses B's use of the pronoun *he*. In B's personal information state s^p_B, *the murderer of Smith* is indistinguishable with *the murderer of Jones*. So he utters ϕ_2 truthfully. Since A does not accept B's statement, only s'_B changes into s''_B and $[x]_{s''_B} = \{\{ic_S, ic_J, ic_{SJ}\}\}$.

$$s'_B[\phi_2] = \{\langle w, g^{+\{x\}}\rangle |\ \langle w, g\rangle \in s,\ g^{+\{x\}}(x) \text{ murdered Smith and Jones in } w\} = s''_B$$

A's negative sentence ϕ_3 is uttered in the common ground $\langle s'_A\{s^p_A\}, s''_B\{s^p_B\}\rangle$ and changes s'_A into s''_A and the $vi \downarrow [x]_{s''_A} = \{ic_S\}$ does not change, as follows:

$$\begin{aligned} s'_A[\phi_3] &= \{\langle w, g^{+\{x\}}\rangle |\ \langle w, g\rangle \in s,\ g^{+\{x\}}(x) \text{ murdered Smith in } w\} \\ &\quad - \{\langle w, g^{+\{x\}}\rangle |\ \langle w, g\rangle \in s,\ g^{+\{x\}}(x) \text{ murdered Jones in } w\} \\ &= \{\langle w, g^{+\{x\}}\rangle |\ \langle w, g\rangle \in s,\ g^{+\{x\}}(x) \text{ murdered Smith \& did not murder Jones in } w\} \end{aligned}$$

A's use of the pronoun is licensed by the existence of the specific individual concept ic_S and no other specific individual concepts in $[x]_{s^p_A}$. Note that the *vi* in B's information state of the common ground is not involved in licensing A's use of the pronoun.

This is contrasted with the case in (2b), where B utters the two sentences ϕ_1 and ϕ_2. They make the common ground into $\langle s_A\{s^p_A\}, s''_B\{s^p_B\}\rangle$. A does not accept B's statements. The *vi* in B's information state of the common ground is $[x]_{s''_B} = \{\{ic_S, ic_J, ic_{SJ}\}\}$. In A's personal information state, there are two *vi*'s which that corresponds to $\{ic_S, ic_J, ic_{SJ}\}$. There is no individual concept ic_{SJ} in $[x]_{s^p_A}$, and ic_S and ic_J are distinguishable in A's personal information state s^P_A: that is, $[x]_{s^p_A} = \{\{ic_S\}, \{ic_J\}\}$. For this reason, A's use of the pronoun is not felicitous. Even if she might try to deny only ϕ_2, it is difficult to divide what is contributed by ϕ_1 and what is contributed by ϕ_2.

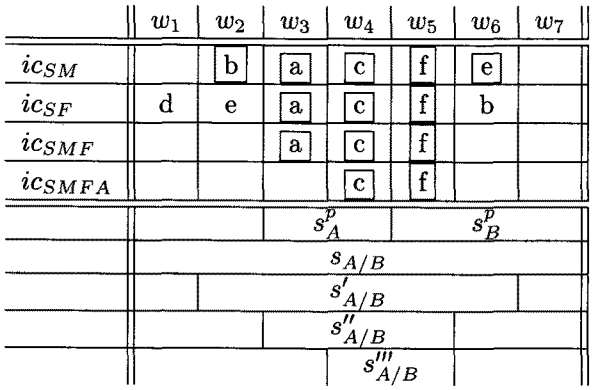
My account for anaphora opens the possibility that at the beginning of a dialog, a new discourse referent is introduced and the hearer does not determine that he can use a pronoun to refer to it. If the speaker adds more information about the *vi*, then the hearer can come to a new information state which allows the speaker to use a pronoun correctly. The following is such a case:

(14) A: A student$_x$ came to see you this morning. Did you see him$_x$?
B: What's his name?
A: I don't know. He$_x$ failed in your class last semester.
B: I see. He$_x$ was going to come this afternoon.

A's first statement does not help B identify who A's talking about. As B gets new information from A's second statement, he becomes sure that there is a unique

student he knows of and who has the properties attributed to him. Now B can use a pronoun to refer to the individual. This can be accounted for in terms of the following four individual concepts.

ic_{SM}:	the student who came to see B this morning
ic_{SF}:	the student who failed in B's class last semester
ic_{SMF}:	the student who came to see B this morning and failed in B's class last semester
ic_{SMFA}:	the student who came to see B this morning and failed in B's class last semester and was going to come this afternoon



From $\langle s_A, s_B \rangle$, the first sentence excludes the possible world w_7 and the information state becomes $s'_{A/B}$. This also changes B's personal information state into $\{w_5, w_6\}$. A's first statement introduces a *vi* in $[x]_{s'_{A/B}} = \{\{ic_{SM}\}\}$ in the common ground. B does not have any other *vi* in his personal information state s^p_B corresponding to this. To be more specific about what she is talking about, A adds the information that the student failed in B's class last semester, which changes $s'_{A/B}$ to $s''_{A/B}$ and changes the *vi* into $[x]_{s''_{A/B}} = \{\{ic_{SM}, ic_{SF}, ic_{SMF}\}\}$. From the information that ic_{SM} and ic_{SF} are the same individual, B's personal information state becomes $\{w_5\}$. Now the *vi* in the common ground is indistinguishable with the *vi* $\{\{ic_{SM}, ic_{SF}, ic_{SMF}, ic_{SMFA}\}\}$ in B's personal information state. This licenses the use of the pronoun by B. Now B knows more than what is known about the individual in the common ground, and utters the last sentence to change the common ground into $s'''_{A/B}$. This example again shows that felicity of anaphora depends on change of information.

Now I will show how (3) is accounted for. To interpret the statements in (3), it is assumed that there are 8 worlds in the context. We also assume that the two speakers in (3) believe that there is only one person who fell off the bridge. With the information state, the first sentence of A's statement in (3) is interpreted as follows:

$$s_A[\exists x[\text{man}(x) \wedge \text{jump-off}(x)]$$
$$= s'_A[\text{man}(x) \wedge \text{jump-off}(x)]$$
$$= s''_A$$

$[x]_{s'_A} = \{\{ic_{WJ}\}, \{ic_{MJ}\}, \{ic_{MF}, ic_{MP}, ic_{MPD}, ic_{MPND}\}\}$
$[x]_{s''_A} = \{\{ic_{MJ}, ic_{MF}\}\}$

If the existential quantifier is interpreted, the variable x takes all possible individual concepts as its values. Then s_A becomes s'_A, which turns into s''_A with the rest of the formula.

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	$g(x) \in s'_A$	$g(x) \in s''_A$	$g(x) \in s'''_B$	$g(x) \in s^p_B$
ic_{WJ}	c	a	b			d	f	e	√			
ic_{MJ}		b	a						√	√		
ic_{MF}	c	b	a	e	d	f			√	√	√	√
ic_{MP}				e	d				√		√	√
ic_{MPD}				e					√		√	√
ic_{MPND}					d				√		√	
				s^p_B								
	$s_A = s_B$											
		s''_A		s'''_B								

Here, ic_{WJ}: the woman who jumped off the bridge
ic_{MJ}: the man who jumped off the bridge
ic_{MF}: the man who fell off the bridge
ic_{MP}: the man who was pushed
ic_{MPD}: the man who was pushed and dead
ic_{MPND}: the man who was pushed but who did not die

Here ic_{WJ}, ic_{MP}, ic_{MPD} and ic_{MPND} are excluded because the individual assigned by the individual concepts in s''_A is not a woman nor pushed in s''_A. In this information state, the variable x takes ic_{MJ} and ic_{MF} in one partition because they are indistinguishable with each other in A's information state. So $[x]_{s''_A} = \{\{ic_{MJ}, ic_{MF}\}\}$.

B does not accept A's statement, so no further update is made with A's statement. In this situation, B tries to find out whether the individual A introduced to the information state corresponds to any individual concept in his own personal information state s^p_B. In his personal information state, B has a *vi* which has a unique partition: $[y]_{s^p_B} = \{\{ic_{MF}, ic_{MP}, ic_{MPD}\}\}$, in which the individual concepts are indistinguishable with each other. B knows of ic_{MP} and notices that ic_{MP} is indistinguishable with ic_{MF} and ic_{MPD} in his own personal information state and ic_{MF} is indistinguishable with ic_{MJ} in A's information state of the common ground. Therefore B concludes that $\{\{ic_{MJ}, ic_{MF}\}\}$ in s_A corresponds to $\{\{ic_{MP}, ic_{MF}, ic_{MPD}\}\}$ in s^p_B. This allows B to use a pronoun to refer to ic_{MJ} when he makes a statement about ic_{MP}.

B's statement is interpreted with respect to $\langle s''_A\{s^p_A\}, s_B\{s^p_B\}\rangle$, but one problem is that no assignment in s_B is defined with respect to the variable x. There must be some step of accommodation of the variable in B's information state in the common ground. This will be dealt with in detail below. For now the first step is to extend the assignment function with the variable introduced in A's information state. Then the

felicity condition for using a pronoun is accommodated in B's information state in the common ground. Here instead of accepting A's statement, B accommodates the information that is carried by the connecting individual concept ic_{MF}: that is, that a man fell off the bridge yesterday. With this, s_B becomes s'_B. The interpretation of the existential quantifier changes s'_B into s''_B. Then the interpretation of the rest of B's statement results in s'''_B.

$$s'_B[\exists y[\text{pushed}(y,x)] = s''_B[\text{pushed}(y,x)] = s'''_B$$
$$[x]_{s'''_B} = \{\{ic_{MP}, ic_{MF}, ic_{MPD}, ic_{MPND}\}\}$$

Dekker and van Rooy (1998) claim, with the following example, that descriptions used to introduce a *vi* are not helpful to decide the individual.

(15) A: A man is sleeping on a park bench.
B: It is not a man, it is a woman, and she is not asleep, she is just sunbathing. Besides, it is not a park bench.

However, A's statement has to play a role in helping B decide an individual in his own personal information state. In this example, it must be true that there is an individual lying at a particular place at the time of utterance. B can identify the individual who A thinks is a man and is sleeping on a park bench with the individual who is a woman and is sunbathing, because B thinks that there is a unique individual lying at the particular place at a particular time. Without this individual concept, there would be no way of licensing the use of the pronoun *it* to refer to the *vi* and assert a factual statement about it.

3.2 Possibility statements

I have shown how a discourse changes the common ground when the utterance is a statement, and discussed how a felicitous use of a pronoun depends on information change. This also applies to statements with modality. The following examples involve a possibility operator.

(16) a. A: A woman is sitting at the bench with a dog.
B: She might have taken my keys.

b. A: A woman is sitting at the bench with a dog.
B: She might be waiting for her husband.

In (16a), A is introducing a woman she is looking at sitting at a bench. B lost his keys at the same bench and knows that someone took his keys. In order to use the pronoun properly, B needs to accept A's statement. When B uses the pronoun *she*, he has the two individual concepts in his information state and he is supposing that the woman sitting at the bench now MIGHT be the one who took his keys: identity between individual concepts is the source of the possibility. In (16b), on the other hand, it is natural to assume that B does not have any woman in mind. This shows that the use of a pronoun in a possibility statement does not require the speaker to have a particular individual in mind. The felicity condition we have given can be satisfied only by accepting (part of) what A says and assuming that

there is a unique individual who has the properties that A attributed to the woman introduced. The pronoun in B's statement simply refers to the woman who is sitting at the bench with a dog.

The difference in the felicity condition for a pronoun in a possibility statement, if ever, comes from the maxim of quality. A possibility statement can be true in at least one possible world in the speaker's personal information state. There has only to be one individual corresponding to the one introduced by A. On the other hand, a statement without the possibility operator must be true in every possible world in the speaker's personal information state, and there must be a corresponding individual in every possible world in it.

Groenendijk, Stokhof and Veltman (= GSV) (1997) claim that in a dialog a more typical case of anaphora involves modality, as in the following:

(17) A: In the park, a man is walking a dog in a loud sweatsuit.
B: (Then) it is Bill.

The discourse occurs in a situation where B knows that Bill often walks a dog. A is looking out the window and tells B about a man who is walking a dog in a loud sweatsuit. Based on his usual observation, B makes the inference that the man must be Bill. GSV claim that anaphora relations between speakers are necessarily inferences and that modality is inherently involved in cross-speaker anaphora. However, the example above is not appropriate for making their claim in two respects. First, B does not have any previous knowledge about a man walking a dog in a loud sweatsuit at this particular time. Knowing that Bill usually walks a dog in a loud sweatsuit is different from knowing that a particular man is walking a dog in a loud sweatsuit at a particular time. In (17), when A introduces the *vi* in the common ground, there is no corresponding *vi* in B's personal information state except the one in the common ground. What B is doing is try to identify the new *vi* with an old one in his personal information state. This is clear from comparison with (3), where B has previous information about the same event and the same man who fell off the bridge.[10] In the example at hand, the pronoun *it* refers to the man who is walking a dog at this particular time, not the man who usually walks a dog AND is walking a dog now. Second, that the man is Bill is not a matter of anaphora, but simply an assertion. So modality can be involved here in identifying a man who often walks a dog with the man who now is walking a dog. An identity statement is felicitously uttered when there has been an assumption that the two *vi*'s have been taken to be different. The felicity condition of anaphora is the assumption, (which I would rather call a presupposition), that they are the same; the identity is not an assertion.

Anaphora itself does not necessarily involve modality. This is clear from the use of a pronoun in (3). B is pretty sure that he knows the man A talked about because B knows the event that is believed to be the same that A talked about,

[10] Here there is an assumption that the event of one man jumping off the bridge in A's knowledge is identified with the event of one man being pushed off the bridge. In one event, we can think of a set of individuals that can be involved. If we talk about two different events or situations, we have two different sets of *vi*'s in the two events: different sets of *vi*'s from different perspectives. This idea is exploited in Aloni (1997).

and the man in question is the participant in the event. This is why we capture the identity as a correspondence relation. If the identity for anaphora is still a possibility or a matter of modality and it is part of the assertion B makes, B could use some expression of modality, as in the following:

(3′) A: A man jumped off the bridge yesterday.
B: ??(Then) He cannot have jumped off, he must have been pushed.

However, the use of modality makes the statement odd. Even if the anaphora relation is a matter of inference, it is not part of the assertion nor expressed with modality. Anaphora requires an indistinguishable *vi*, so if the condition is believed to be met, it is just assumed. In (2), the identity of the murderer of Jones and the murderer of Smith is what B believes to be a fact. In (16), A and B know the identity of the student who visited the office and the one who failed in B's class as a fact.

3.3 Meaning of a licensed pronoun

The felicity condition for a proper use of a pronoun requires the unique *vi* in the information state for the antecedent and a corresponding unique *vi* in the personal information state for the pronoun too. However, a personal information state is not available in the common ground. One way to capture the condition on the personal information state is to derive the personal information state on the basis of the relation of epistemic alternativeness. This is what I am going to do.

Interpretation of a pronoun is simply an individual concept, but the felicity condition requires a lot more. As we said in relation to (10), a pronoun refers to an antecedent, a *ic* it takes as a value must be a specific *ic*, or indistinguishable to the *sic*, in the information state for the antecedent as well as in his or her personal information state. This must be reflected in the interpretation of a pronoun. Under the assumption that the context c is $\langle \alpha, \beta, t \rangle$ and that α uses a pronoun to refer to the antecedent introduced by β, the interpretation of the pronoun can be given as follows:

$\langle s_\alpha, s_\beta \rangle [P(\text{he}_x)]^c = \langle s_\alpha [P(\text{he}_x)]^c, s_\beta \rangle$, where $c = \langle \alpha, \beta, t \rangle$ and;
$s_\alpha [P(\text{he}_x)]^c = \{\langle w, g \rangle \in s_\alpha \mid g(x)(w) \in F(P)(w)\}$,
which is defined if

- for every g in s_α, $x \in dom(g)$;
- there is a specific individual concept *sic* in $s_{\alpha/\beta}$ which is fully defined in $EpistAlt(\alpha, w)$;
- for any two assignments g, g' in $ran(s_\alpha)$, $g(x)$ and $g'(x)$ are indistinguishable in all possible worlds in $dom(s_\alpha/\beta)$ and $EpistAlt(\alpha, w)$, if they are defined in the the possible worlds.[11]

– $ran(\gamma)$ is the range of γ.
– $EpistAlt(\alpha, w) = \{w' \in W \mid w'$ is compatible with what α knows in $w\}$
– An individual concept *ic* is fully defined in an information state s iff $dom(s) \subseteq dom(ic)$.

When a pronoun is used by α to refer to an antecedent introduced by β, there must be a unique *vi* in the information state for the antecedent and a unique *vi* in the personal information state of the pronoun user. However, the personal information state is not defined in the common ground. Instead, there must be a specific individual concept *sic* in the *vi* of s_β which is fully defined in the belief context of the pronoun user. Each individual in each individual concept *ic* must have the properties that determine the *ic* itself. From this condition, all assignments in $s_{\alpha/\beta}$ which assign to the variable x an individual concept in which only part of the individuals have the properties attributed to the individual concept are eliminated from $s_{\alpha/\beta}$. If an individual concept is fully defined in every possible world in $EpistAlt(\alpha, w)$, the agent α can be assumed to believe the information attributed to the individual concept.

The felicity condition behaves as a presupposition. If it is not satisfied at the current information state, it is accommodated in this way. First, the variable for the pronoun is added to the assignments in the information state of the pronoun user. Second, the information attributed to the connecting *sic* is added to s_α. Third, the use of a pronoun eliminates assignments which assign an individual concept which assigns an individual who does not have the properties attributed to the individual concept itself.

This is illustrated in (3). In (3), A's statement is not accepted by B, but B uses a pronoun felicitously. Thus it does not directly change B's information state. To interpret a pronoun in B's statement properly, however, we have to adjust B's information state so that the variable A has introduced is available to B too. What is further required to use a pronoun felicitously is to make the pronoun refer to a specific *ic*'s like *the man who fell off the bridge* which is defined in possible worlds in B's information state and personal information state. This is the effect of accommodation.[12]

Since a personal information state is not directly available in the common ground, if a pronoun is used, it is assumed in most cases that it is felicitously used, with no evidence against it. This is illustrated in (18). Suppose that B believes that there is only one man who bought a crossbow at a particular gun shop and who killed Smith and Jones. A believes there are two men who bought a crossbow at the same gun shop, and that one man killed Smith and the other Jones. In a common ground $\langle s_A, s_B \rangle$, the following conversation can be considered:

(18) B: A man bought a crossbow at the gunshop at Louisville Road.
A: ?He murdered Smith yesterday.

---

[11] The condition can be given globally, not pointwise:

i. There is an *ic* in $[x]_{s_\alpha}$ which is fully defined in $\bigcup_{w \in dom(s_\alpha)} EpistAlt(\alpha, w)$ and every *ic* in $[x]_{s_\alpha}$ which is defined in $\bigcup_{w \in dom(s_\alpha)} EpistAlt(\alpha, w)$ is indistinguishable in $EpistAlt(\alpha, w)$.

However, the felicity condition globally formulated does not appropriately select each possible world which satisfies the condition.

[12] As pointed out in Yeom (1998), a presupposition is accommodated so that it has the strongest effect on the context. This means that when a presupposition is accommodated, we try to accommodate the strongest *vi* possible that is compatible with the context.

B: He also killed Jones.
A: No, Jones was killed by another man who had bought a crossbow at the same shop.

In this example, the pronoun in A's first statement is not appropriate, but B does not know this and simply believes that A believes that there is a unique man who bought a crossbow at the gunshop and that he murdered Smith. He tells her that there were two murder cases. A's final statement indicates that the pronoun in her first statement is not felicitously used. This infelicity can be captured because the felicity condition requires that if the individual concept is defined in a possible world, there be a unique individual which has the properties carried by the individual concept. In the example, the felicitous use of A's pronoun requires that there be a unique individual in A's epistemic worlds which has the property of buying a crossbow at the particular gunshop at a particular time. A's second statement requires more than one buyer of a crossbow, which leads to the absurd state.

3.4 Anaphora in non-statements

3.4.1 Interpretation of interrogatives. Asking a question does not really change the common ground. Assuming that the meaning of a question is a set of possible answers or propositions, asking a person α a question is partitioning α's information state in the common ground and telling α to say which answer or partition is true according to what α personally knows. Here possible answers are formed from the common ground. Thus we do not have to consider personal information states of the conversational participants. Take a *Yes-No* question for example. Suppose the common ground is $\langle s_A, s_B \rangle$, ignoring personal information states, and that a context c is $\langle A, B, t \rangle$. Then the common ground is updated with a question and an answer as follows:

$$cg[Y|N? : \phi]^c = \langle s_A, \{s_B[\phi], s_B[\neg\phi]\}\rangle$$
$$cg[Qx? : \phi]^c = \langle s_A, \{\{\langle w, g\rangle \in s_B[\exists x\phi] |\ g(x) = ic, w \in dom(ic)\} |\ ic \in IC\}\rangle$$
$$\{s_1, \ldots, s_n\}[(Y/N)\phi] = \bigcup\{s_i[\phi] |\ s_i \in \{s_1, \ldots, s_n\}\}$$

Here a *Yes-No* question, which is represented as "$Y|N? : \phi$", generates two alternative updates. A *Wh*-question is treated like a statement with the existential quantifier, but the resulting state is partitioned according to the individual concept assigned to the variable. The meaning of an answer is to collect the partitions in which the answer is true. More precisely, each of the partitions is updated with the answer, and the resulting partitions are merged. The effect of partitioning is just to determine the appropriateness of an answer. And I assume that "Yes/No" has no semantic contribution, but that the rest of the answer does. This is illustrated in the following:

(5) A: A student$_x$ stopped by (to see you this morning).
$(= \exists x[\text{student}(x) \wedge \text{stopped-by}(x)] = \phi_1)$
B: Did he turn in a paper$_y$? $(= Y|N? : \phi_2?)$
A: Yes, he did. He put it on your desk. $(= \phi_3; \phi_4)$

Suppose that we begin with the common ground $cg = \langle s_A, s_B \rangle$. After A's first statement is interpreted and B accepts it, the common ground becomes the following:

$$cg[\phi_1]^{\langle A,B,t \rangle} = cg' = \langle s'_A, s'_B \rangle, \text{ where}$$
$$s'_{A/B} = \{\langle w, g \rangle \in s |\ g(x)(w) \text{ stopped by this morning in } w\}$$

Next, the new common ground is updated with B's question, as follows:

$$cg'[Y|N? : \phi_2]^{\langle B,A,t' \rangle} = \langle \{s'_A[\phi_2],\ s'_A[\neg\phi_2]\} (= s''_A),\ s'_B \rangle$$

The interrogative contains a pronoun. In such cases, the felicity condition for the use of a pronoun is expected to be different from that for a pronoun in a statement. A statement is made based on the speaker's personal information. On the other hand, a question does not have to be based on the speaker's personal information state. It need not be verified in the personal information state. So in the example above B can use a pronoun only based on (part of) what A said: B has only to accept (part of) what A says and assume that it refers to a unique *vi*. It is possible that B has some previous knowledge about the individual A has introduced. But this is not a requirement for asking a question.

3.4.2 Interpretation of imperatives. A command can be taken to be an action which becomes part of a plan for a goal, following Segerberg (1990). He expresses an action as a set of pairs of possible worlds $\langle w, w' \rangle$, where the first world is a state of affairs in which the action can be performed, and the second world is an outcome of performing the action in the first world. Then we can get an action from a proposition via a function δ.

For a given proposition p, the corresponding action $\delta(p)$
$= \{\langle w, w' \rangle \in W \times W$: w is compatible with $p \wedge w' \in p\}$

In a dynamic setting, the first possible world w is one of the possible worlds in the common ground, and it is compatible with the proposition p corresponding to the imperative, and p is true in the second possible world w'. We could consider w' a temporal continuation of w in some sense.[13] We can imagine that there are a lot of restrictions on the relationship between worlds like w and those like w', but we are not concerned with it here.

To interpret an imperative in dynamic semantics, we need to incorporate the component of someone's plan in the common ground. One way to do it is to assume that a common ground has an intentional component, separately from the epistemic component. In such an analysis, however, some possible interactions between the epistemic and intentional components are hard to deal with. When a command is interpreted, we consider assignments for the epistemic component as well as those

[13] A possible world here is like a stage. We can think of a relation of precedence between possible worlds: $w \prec w'$ means 'w precedes w'' or 'w' is a temporal extension of w. For a possible world, there are an infinite number of temporal extensions, and a proposition from a command will be true in a subset of them.

for the intentional component. It is also possible that a pronoun in a statement refers to something introduced in a command if the statement is about a situation after the command is realized as an action. An imperative can be uttered with some preconditions for the appropriateness of the command, and the preconditions must be satisfied in the epistemic component. In the analysis, these interactions must be dealt with separately.

To overcome the possible problems, it is necessary to deal with epistemic and intentional components at the same time. It is possible if we assume that an information state is a set of $\langle w, g, w' \rangle$, where w is compatible with the plans of an agent and w' is a possible world in which the plans are accomplished. Ordinary statements only change the information state through the first possible world, and commands change the information state through the second possible world (and the first possible world through the condition of compatibility). This is a more flexible way of dealing with commands. In this case, an assignment g contains variables introduced in commands as well as those introduced in statements. This opens the possibility of dealing with bidirectional coreferences between variables from statements and those from commands. Assuming that the current utterance context $c = \langle A, B, t \rangle$, a command updates a common ground and an information state in it as follows:

$\langle s_A, s_B \rangle[!\phi]^c = \langle s_A, s_B[!\phi]^c \rangle$
$s[!P(you, x)]^c = \{\langle w, g, w' \rangle \in s |\ \phi$ is realizable in w,
$\quad \langle \text{you}^c, g(x)(w') \rangle \in F(P)(w')\}$
$s[!\exists x\phi] = \{\langle w, g^{+\{x\}}, w' \rangle \mid \langle w, g, w' \rangle \in s\}[!\phi]$
ϕ is realizable in w iff there is at least one possible world w''
$\quad$ such that w is an ancestor of w'' and ϕ is true in w''.
w is an ancestor of w'' (or, w'' is a descendant of w)
$\quad$ iff there is zero or more successors w''' between w and w''.

We can define different rules for different formulas than the ones we have here: they are all reflected on the second possible world in each triple.[14]

Now I will show how the imperative in (6) is interpreted. It is repeated here:

(6) A: There is an engine at Avon. ($= \exists x[\text{engine}(x) \wedge \text{at}(x,\text{Avon})] = \phi_1$)
B: Send it to Bath. ($= !\text{send}(\text{you},x,\text{Bath}) = \phi_2$)

The first sentence is uttered by A and accepted by B, which updates the common ground as follows:

(19) $\langle s_A, s_B \rangle[\phi_1]^{\langle A,B,t \rangle} = \langle s'_A, s'_B \rangle$, where
$s'_{A/B} = \{\langle w, g^{+\{x\}}, w' \rangle |\ \langle w, g, w' \rangle \in s_{A/B}$, $g^{+\{x\}}(x)(w) \in F(\text{engine})(w)$,
$\quad g^{+\{x\}}(x)(w)$ is at Avon$\}$

At a context $c = \langle B, A, t \rangle$ and in an information state as specified in $\langle s'_A, s'_B \rangle$, an imperative has the meaning of adding an action to A's plan p_A, as shown below:

[14] There are some linguists that imperatives are also sentences with modality. Even if a command involves something like deontic modality, it is different from a statement with deontic modality in some respects.

$\langle s'_A, s'_B\rangle[!\phi_2]^{\langle B,A,t\rangle} = \langle s''_A, s'_B\rangle$, where
$s''_A = \{\langle w, g^{+\{x\}}, w'\rangle \in s'_A \mid \langle A, g^{+\{x\}}(x)(w'), Bath\rangle \in F(\text{send})(w')\}$

When the imperative is interpreted, an action from the imperative is added only to A's plan: the action with a pronoun is added to the same information state as that for its antecedent. This allows a proper use of a pronoun only by accepting what A says. The reason is that the proposition from the command must not be already true in B's personal information state, nor the command is in B's plan. The felicity condition for a pronoun can be satisfied by only accepting what A says. In the example above, the engine introduced in A's statement, in principle, must not split into two or more distinctive virtual individuals in B's personal information state. However, since B's command does not have to be already established as a true proposition or an actual plan in his personal information state, the felicity condition can be satisfied only in B's information state of the common ground. This in turn can be satisfied by accepting what A says and assuming that there is a unique *vi* corresponding to the unique *vi* in A's information state of the common ground.

So far I have discussed declaratives, questions and imperatives. Statements directly change the common ground on the basis of the speaker's own personal information state. Thus a statement is about a virtual individual in the speaker's personal information state which corresponds to a virtual individual introduced by another speaker. Questions and imperatives do not require separate virtual individuals, independently of the ones introduced by the antecedents. Neither of them conveys any factual information which requires a separate virtual individual in the speaker's own personal information state. For this reason, the felicity condition for anaphora can be satisfied by only accepting the virtual individual introduced by the antecedent.

4. Conclusion

I have shown how the dynamic aspects of anaphora interact with the felicity conditions. In my account, one crucial thing is that to capture the dynamic aspects, variables are assumed to range over individual concepts which are ordered among themselves w.r.t. informativeness. As information is accumulated about an individual, the set of individual concepts that connect two individuals across speakers change. This captures the dynamic aspect of anaphora. Anaphora about a variable is licensed when one unique virtual individual in one information state does not split into two or more distinctive virtual individuals in another information state. This allows us to account for asymmetric characteristic of anaphora.

In this paper, I wanted to show how anaphora across speakers is licensed. Anaphora across speakers can be explained on the basis of information: at least the attributions to an individual when it is introduced in the common ground are important in restricting anaphora. This can be applied to anaphora across agents of belief. One difference from anaphora across speakers is that even if the correspondence relation between virtual individuals in two different information states is based on the speaker's personal information state, it may not be established on

the basis of attributions to the antecedent that are actually mentioned in statements. However, even arbitrary correspondence relations between virtual individuals across two different information states can be captured by virtual individuals (or, individual concepts). It is more likely that the correspondence relations are established in previous conversations with someone else.

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Submitted on: November 7, 2010
Accepted on: December 17, 2010