Sense and Reference in Dynamic Semantics

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1 Introduction

The dynamic approach to semantic interpretation (Kamp 1980; Heim 1982; Barwise 1987; Rooth 1987; Groenendijk and Stokhof 1992) provides a framework in which a proform can be related to an antecedent across sentence boundaries. While this approach has been very fruitful, it has been limited in two important ways. First, only anaphora involving NP's has been considered.[1] Thus, while example (1), involving anaphora between "her" and "a woman", is treated in the dynamic framework, example (2), involving anaphora between VP's, is not treated.[2]

(1) John saw **a woman**. Harry saw her too.

(2) John **walked**. Harry did too.

The second limitation in dynamic semantics is that a pronoun is always interpreted as denoting the same individual as its antecedent. In example (1), the pronoun "her" denotes the same individual as the NP "a woman". I will describe this as *identity of reference*. Applied to VP anaphora, identity of reference requires that the anaphoric (elided) VP must denote the same property as its antecedent. In (2), Harry and John both have the same property, that of walking.

It is well known that a proform does not always denote the same object as its antecedent. Instead, a proform and its antecedent can represent the same *way of selecting an object*. I will term this *identity of sense*. Examples (3) and (4) illustrate identity of sense for NP and VP anaphora, respectively.

(3) Smith makes **his children** go to bed at 8 every night.
Jones lets them stay up as late as they want.

(4) If Tom was having trouble in school, I would **help him**.
On the other hand, if Harry was having trouble, I doubt that I would.

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[1]One exception to this is Klein (1987), which is a DRT treatment of VP anaphora. This work is suggestive of the uniform treatment of VP and NP anaphora advocated here. Klein's approach largely duplicates the empirical predictions of the Sag/Williams approach. Problems with the Sag/Williams approach are discussed in Section Seven.

[2]Example (2) is generally described as VP deletion or VP ellipsis, while the term VP anaphora is often reserved for "do it" anaphora. I will use the term VP anaphora to cover all such cases.

In (3), the pronoun "them" does not denote the same set of children as the antecedent, "his children". Similarly, in (4), the elided VP is interpreted as the property of *helping Harry*, while its antecedent represents a different property, that of *helping Tom*. I will show that the anaphoric dependence in both examples can be characterized as identity of sense.

In this paper, I will propose two extensions to the system of Dynamic Predicate Logic (Groenendijk and Stokhof 1992) to allow anaphora involving VP's as well as NP's, and to allow identity of sense as well as identity of reference.

To accomplish the first extension, it is necessary to add property variables to the domain of the assignment function. Furthermore, it is necessary to introduce a mechanism allowing overt VP's to modify the assignment function, so that they can function as antecedents in subsequent discourse. The simplest way of doing this in dynamic semantics is to treat VP's as indefinite property expressions. This permits VP anaphora without any other modification to the dynamic framework; the treatment of NP anaphora and VP anaphora is entirely uniform.

The second extension is to allow variables to denote *senses* rather than *referents*, where an NP sense is a function from an assignment function to an individual, and a VP sense is a function from an assignment function to a property.[3] Thus a proform need not designate the same object as its antecedent; rather, the proform and antecedent must represent the same function from assignments to objects. In example (3), "them" and "his children" represent the same function from assignments to (plural) individuals. Because this function is evaluated in two different contexts, it selects two different plural individuals. Similarly, identity of sense anaphora permits "sloppy identity" in example (4), both the elided VP and its antecedent represent the function *helping a salient individual*.

I will show how these two simple extensions account for examples (2) - (4) in dynamic semantics. In addition, I will explore several further empirical consequences of the resulting system. In particular, I will show that this approach predicts a range of heretofore unobserved "sloppy identity" cases. Furthermore, it makes it possible to state a general constraint on sloppy identity, requiring that there be two contrastively stressed controllers for the sloppy variable.

In what follows, I begin with a brief account of the system of Dynamic Predicate Logic (DPL). Next, I extend DPL for VP anaphora and for identity of sense anaphora. I show that the resulting system predicts a broader range of sloppy identity phenomena than has previously been discussed in the literature. I briefly examine the Sag/Williams approach to sloppy identity, followed by consideration of more recent alternatives. In addition, I compare the proposed approach with the interpretation of variables in dynamically scoped programming languages. Finally, I examine some issues for further research.

[3]See Groenendijk and Stokhof (1990) for a discussion of this notion of *sense* in dynamic semantics. I will not discuss the way in which sense might be extended to intensional phenomena.

2 Background: Dynamic Predicate Logic

In dynamic approaches to semantics such as DPL, meanings are not truth conditions, but potentials for changing the information state of the interpreter. In particular, one aspect of such information states has been addressed: the ability of a discourse to support subsequent anaphoric expressions. In DPL, an information state is an assignment function, and a sentence meaning relates an input assignment function to an output assignment function.

DPL is concerned primarily with two phenomena: intersentential anaphora and donkey anaphora. My interest in this paper is with intersentential anaphora, such as the following example:

(5) A man walks in the park. He whistles.

As Groenendijk and Stokhof point out, a standard logical translation of this sentence would be:

$$\exists\ x[\text{man}(x) \wedge \text{walk\_in\_the\_park}(x)] \wedge \text{whistle}(x)$$

In this representation, the final occurence of x appears to be outside the scope of the existential quantifier. It is a central feature of all dynamic approaches to semantics that the existential quantifier is "dynamic" – it can bind variables across sentence boundaries. In DPL, the dynamic nature of existential quantification is expressed in terms of the relation of the input and output assignment functions, so that the meaning of a simple existentially quantified sentence is the following:[4]

Dynamic Existential Quantification:

$$[\![\ \exists x\ Px\ ]\!] = \{<g,h> \mid h[x]g\ \&\ h(x)\ \epsilon\ F(P)\ \}$$

For a given input assignment function g, the possible output assignment functions h are those such that the individual h(x) has the property F(P). This information is made available to subsequent discourse because the output function h will become the input function to a subsequent sentence. This is stated in the following dynamic conjunction rule:

Dynamic Conjunction:

$$[\![\ \phi \wedge \psi\ ]\!] = \{<g,h> \mid \exists\ k{:}\ <g,k>\ \epsilon\ [\![\ \phi\ ]\!]\ \&\ <k,h>\ \epsilon\ [\![\ \psi\ ]\!]\ \}$$

Here, the output assignment function of ϕ is k, which becomes the input assignment function for ψ. Together, these two rules permit an existential quantifier to bind a variable in subsequent discourse, as shown by the following derivation:

[4] In this formula, the notation **h[x]g** is to be understood as "h is exactly like g at all values in its domain, except possibly x".

$$[\![\exists \text{ x: man(x).walks-in-the-park(x)} \wedge \text{whistles(x)}]\!] =$$

$$\{\langle g,h\rangle \mid \exists \text{ k: } \langle g,k\rangle \in [\![\exists \text{ x: man(x).walks(x)}]\!] \;\&\; \langle k,h\rangle \in [\![\text{whistles(x)}]\!] \} =$$
$$\{\langle g,h\rangle \mid h[x]g \;\&\; h(x) \in F(man) \;\&\; h(x) \in F(walks) \;\&\; h(x) \in F(whistles) \}$$

The reader is referred to Groenendijk and Stokhof (1992) for the complete syntax and semantics of the DPL system.

3 Extending DPL for VP Anaphora

I will now extend DPL for VP anaphora, as illustrated by examples such as (2), which is repeated here:

(2) John **walked**. Bill did too.

I will represent the anaphoric (or elided) VP as a property variable. Thus, I will extend the semantic language to include property variables. This means that the assignment function now assigns individuals or properties to each variable, where property variables are written in uppercase.

In DPL, an antecedent is made available to subsequent discourse through dynamic existential quantification. Thus, the simplest way to extend DPL for VP anaphora is to represent overt VP's as indefinite property expressions. This resembles the "Davidsonian" approach to logical representation of sentences (Davidson 1980), in which the representation of "John walked" is "something happened, it was an instance of walking, and John did it." More formally,

"John walks" $\Rightarrow \exists$ X:walking(X). John did X.

Given this representation[5], the possibility of VP anaphora follows directly. The logical representation for (2) is now:

$\exists$ X:walking(X). John did X. Bill did X.

The meaning for (2) can be derived with the existing DPL rules for existential quantification and dynamic conjunction, as follows:

[5]Note that this differs from Davidson's proposal in two important respects: first, it applies to all VP's, whereas Davidson's proposal is restricted to action sentences. Second, the existentially quantified variable is a property, while in Davidson's proposal it is an individual.

$\exists$ X:walking(X). John did X. Bill did X. =

$$\{\langle g,h \rangle \mid \exists k{:}\langle g,k \rangle \in \llbracket \text{exists } X{:}\text{walking}(X).\ \text{did}(\text{John}, X) \rrbracket \ \& \ \langle k,h \rangle \in \llbracket \text{did}(\text{Bill},X) \rrbracket \} =$$

$$\{\langle g,h \rangle \mid \exists k{:}k[X]g \ \& \ \text{walking}(k(X)) \ \& \ \text{did}(\text{John}, k(X)) \ \& \ h = k \ \& \ \text{did}(\text{Bill},k(X)) \} =$$

$$\{\langle g,h \rangle \mid h[X]g \ \& \ \text{walking}(h(X)) \ \& \ \text{did}(J,h(X)) \ \& \ \text{did}(\text{Bill},h(X)) \}$$

With VP's represented as existentially quantified property variables, the DPL system permits intersentential VP anaphora in just the same way that it permits intersentential NP anaphora.

4 Extending DPL for Identity of Sense

Next, I will extend DPL to account for identity of sense anaphora. Consider first a simple case of "sloppy identity" in VP anaphora:

(6) A man **saw his cat**. A boy did too.

Under the "sloppy" reading, the interpretation is *A man saw his cat, A boy saw the boy's cat.* To account for this reading, I will allow variables to denote senses as well as referents. A VP-referent is a property, while a VP-sense is a function from assignments to properties. Similarly, an NP-referent is an individual, while an NP-sense is a function from assignments to individuals. Thus, the elliptical VP in (6) denotes the same sense as the antecedent VP, but not the same referent.[6]

To permit identity of sense anaphora, it is necessary to modify the dynamic existential quantification rule of DPL. Recall that in DPL, the existential quantifier changes the input assignment function by associating an individual with the index of the quantified variable. Above, I extended this so that an existential quantifier changes the assignment function by associating a property with a variable. For identity of sense anaphora, the existential quantifier must be able to associate a *sense* with an index, as follows:

$$\exists\ x{:}\phi.\psi = \{\langle g,h \rangle \mid \exists\ k{:}k[x{:}\phi]g \ \& \ \langle k,h \rangle \in \llbracket \psi \rrbracket \}$$

The sense ϕ associated with the existential quantifier is "stored" as the value of the assignment function k at the index x. In many cases, ϕ will simply be a constant function, λ g.x – that is, at any context, it will denote the same object.

[6] One could analyze such examples as identity of reference anaphora, with the elliptical VP and its antecedent sharing the referent λ *x.x saw x's cat.* This observation forms the basis for the Sag/Williams λ-abstraction approach to VP anaphora, which I discuss in Section Seven.

However, if ϕ contains a context-dependent variable, it will not be a constant function.

Now, a variable x will "retrieve" the sense that is stored at index x. This sense is a function of context, thus, it must be applied to the current context. This is reflected in the following rule for variable interpretation:

$$[\![\text{x}]\!]_g = (\text{g(x)})(\text{g})$$

Thus to interpret a variable x at assignment function g, the value of x at g is determined and this value is then applied to the assignment function. This makes it possible to derive a sloppy reading whenever there is an appropriate change in the context. The following is a derivation of the sloppy reading for (6) in the modified system:

$\exists$ X:seeing x_1's cat(X). $\exists\, x_1$. man(x_1) $\wedge$ did(x_1,X). $\exists\, x_1$. boy(x_1) $\wedge$ did(x_1,X) =

{<g,h> | $\exists$k:<g,k> ϵ $[\![$ $\exists$ X:seeing x_1's cat(X). $\exists\, x_1$. man(x_1) $\wedge$ did(x_1,X). $]\!]$ &
<k,h> $\epsilon[\![$ $\exists\, x_1$. boy(x_1) $\wedge$ did(x_1,X) $]\!]$ } =

{<g,h> | $\exists$k:k[X:seeing x_1's cat]g & $\exists$ l:<k,l> ϵ $[\![$ $\exists\, x_1$. man(x_1) $\wedge$ did(x_1,X) $]\!]$
& <l,h> ϵ $[\![$ $\exists\, x_1$. boy(x_1) $\wedge$ did(x_1,X) $]\!]$ } =

{<g,h> | $\exists$k:k[X:seeing x_1's cat]g & $\exists$ l:l[x_1]k & man(l(x_1)) &
did(l(x_1),l(X)(l)) & h[x_1]l & boy(h(x_1)) & did(h(x_1),h(X)(h)) } =

{<g,h> | $\exists$k:k[X:seeing x_1's cat]g & $\exists$ l:l[x_1]k & man(l(x_1)) &
did(l(x_1),seeing l(x_1)'s cat) & h[x_1]l & boy(h(x_1))
& did(h(x_1),seeing h(x_1)'s cat) }

In this example, sloppy identity is possible because "a boy" *re-uses* the index used by "a man" and changes the assignment function value at that index. This is permitted in DPL; there is no novelty condition on indices. Since an existential quantifier changes the assignment function at the variable index, "a man" is not the antecedent for "a boy", despite the fact that they have the same index. The sense of the elliptical VP is identical to that of the antecedent: *seeing* x_1*'s cat*. This is a function from assignment functions to properties. The property is fixed based on the value that the assignment function gives to x_1. It is this value that is changed in the discourse between the antecedent and the elliptical VP; the value of x_1 changes from the man to the boy. If "a boy" does not re-use the index of "a man", the strict reading is derived.

It would appear that sloppy identity is somehow dependent on the occurrence of an existential quantifier: it is because "a boy" is translated as an existential quantifier that it can change the assignment function before the interpretation of the elliptical VP. However, we do not wish to restrict ourselves to this, since sloppy identity is equally possible in the following example:

(7) John **saw his cat**. Bill did too.

Here, the controller of the sloppy variable is a name, "Bill". In the next section, I will suggest that "Bill" is contrastively focused with "John" in this example, and that contrastive focus is the crucial factor in permitting sloppy identity.

5 Contrastive Focus and Sloppy Identity

We have seen that any focused expression can change the input assignment function at its index. I will notate a focused expression in uppercase, and always interpret focused expressions as changing the input assignment function. Contrastive focus arises from the coindexing of assignment-changing expressions. Thus, a contrastively focused expression is coindexed with its "antecedent".[7]

Now, we can give the following logical translation for (7):

$\exists$ X:seeing x_1's cat(X). did($JOHN_1$,X) $\wedge$ did($BILL_1$,X)

In other words, *BILL* is related to *John* in the following way: *Bill* re-uses *John*'s index, and also changes the value of the assignment function at that index. This reflects the fact that *Bill* and *John* are related by contrastive focus. Now, the derivation of (7) proceeds similarly to that of (6):

$\exists$ X:seeing x_1's cat(X). $JOHN_1$ did X. $BILL_1$ did X. =

$\{$<g,h> | $\exists$k:<g,k> ϵ $[\![$ $\exists$ X:seeing x_1's cat(X). did($JOHN_1$, X) $]\!]$ &
<k,h> $\epsilon[\![$ did($BILL_1$,X) $]\!]$ $\}$ =

$\{$<g,h> | $\exists$k:k[X:seeing x_1's cat]g & $\exists$ l:<k,l> ϵ $[\![$ did($JOHN_1$, X) $]\!]$ &
<l,h> ϵ $[\![$ did($BILL_1$,X) $]\!]$ $\}$ =

$\{$<g,h> | $\exists$k:k[X:seeing x_1's cat]g & $\exists$ l:l[x_1]k & named(l(x_1),John) &
did(l(x_1),l(X)(l)) & h[x_1]l & named(h(x_1),Bill) & did(h(x_1),h(X)(h)) $\}$ =

$\{$<g,h> | $\exists$k:k[X:seeing x_1's cat]g & $\exists$ l:l[x_1]k & named(l(x_1),John) &
did(l(x_1),seeing l(x_1)'s cat) & h[x_1]l & named(h(x_1), Bill)
& did(h(x_1),seeing h(x_1)'s cat) $\}$

The meaning of focus on an element e_x, then, is that the value of the assignment function is (possibly) different at the index x. For contrastive focus between elements α and β, β re-uses the index used by α, but also changes the value of the assignment function at that index.

[7] See Rooth (1992a) for discussion of the relation between contrastive focus and antecedence.

Note that sloppy identity can only occur in this system when the assignment function is changed by this re-use of an index. Now, apart from the case of contrastive focus, we will impose a novelty condition[8] on indices, such that no (non-focused) operator can use an index previously used in discourse. This means that sloppy identity is only possible as covariance between contrastively focused controllers.

In general, sloppy identity requires the interaction of two anaphoric expressions, so that a proform is contained within the antecedent for another proform. The configuration for sloppy identity is as follows:

General Sloppy Identity Configuration:
C1 $\ldots [_{XP} \ldots [_{YP}] \ldots] \ldots$ C2 $\ldots [_{XP'}]$

Here, C1 and C2 are the controllers of sloppy variable YP, which is contained in XP. XP in turn is the antecedent for XP′. Thus, whenever antecedent XP contains a proform YP, YP can be sloppy – that is, it can covary with controllers C1 and C2.. In the proposed system, the sloppy reading arises when C2 *re-uses* the index of C1, changing the value of the assignment function at that index. Furthermore, we have imposed the following novelty condition, restricting the re-use of indices:

Novelty Condition: an index i can be re-used by a new binder α only if there is a previously occurring expression β_i, where α and β are related by contrastive focus.

This novelty condition results in the following constraint on sloppy identity:

Contrastive Parallelism Constraint: Sloppy identity is possible only if C1, C2 are contrastively stressed.[9]

In sum, sloppy identity is extremely flexible, but strongly constrained by focus structure. Any embedded variable can be sloppy, as long as the two controllers are related by contrastive focus. In the examples given up to this point, the sloppy variable has been an NP, and the containing expression, a VP. Note that the account given here applies uniformly to both NP-meanings and VP-meanings. This predicts that there should be four different possible structures for sloppy identity. In the next section, I show that this prediction is borne out, bringing to light cases of sloppy identity that have not previously been observed in the literature.

[8]Novelty conditions on indices have been discussed widely in the literature on dynamic semantics. See Chierchia (1992) for a general proposal, and Kratzer (1992) for a novelty condition for focused elements.

[9]See Rooth (1992b) for a similar proposal, relating sloppy identity to focus structure. In addition, several authors have proposed a parallelism constraint on sloppy identity, including Fiengo and May (1992) and Prüst et al. (1991). These proposals require structural parallelism between controllers, rather than a contrastive focus relation. See Hardt (1992; 1993) for criticisms of a structural parallelism constraint on sloppy identity.

6 Sloppy Identity: Four Categories

Since we are treating VP anaphora and pronominal anaphora uniformly, there are actually four possibilities that fall under the General Sloppy Identity Configuration:

Four possibilities: XP,YP ϵ {NP,VP}

$[_{XP}\ [_{YP}]]$	
	C1 XP YP C2 XP′
$[_{VP}\ [_{NP}]]$	1. Susan $[_{VP}$ **loves** $[_{NP}$ **her**] **cat**]. Jane does $[_{VP}$] too.
$[_{NP}\ [_{NP}]]$	2. Smith puts $[_{NP}$ $[_{NP}$ **his**] **children**] to bed at eight every night. Jones lets $[_{NP}$ them] stay up as late as they want.
$[_{VP}\ [_{VP}]]$	3. I'll help you if you $[_{VP}$ **want me to** $[_{VP}$]]. I'll kiss you even if you don't $[_{VP}$].
$[_{NP}\ [_{VP}]]$	4. When Harry drinks, I always conceal $[_{NP}$ **my belief that he shouldn't** $[_{VP}$]] . When he gambles, I can't conceal $[_{NP}$ it].

(1) is the well-known case of sloppy identity in VP anaphora. Here, C1 is *Susan* and C2 is *Jane*. The sloppy variable *her* is contained in a VP antecedent. (2) also illustrates a well-known structure, variously labelled "paycheck pronouns" or "pronouns of laziness".[10] Here the two controllers are *Smith* and *Jones*, and the sloppy variable is *his*. This time, the sloppy variable is an NP contained in an NP antecedent.

(3) and (4) are cases that have not previously been discussed in the literature, to my knowledge.[11] In (3), the sloppy variable is an elliptical VP, embedded in a VP. The two controllers are *help you* and *kiss you*. In (4), the sloppy variable is again an elliptical VP, this time contained in a VP. The controllers are *drinks* and *gambles*. All four cases receive a straightforward treatment in the extended DPL system described here.[12]

7 Alternative Approaches

In this section, I briefly compare the proposed approach with some alternative semantic approaches to sloppy identity and anaphora. I begin with the

[10] "Paycheck pronouns" are discussed by Cooper (1979) and Engdahl(1986), among others.

[11] Example (3) was provided to me by Marc Gawron, who attributes it to Carl Pollard.

[12] There is a problem with cases (2) and (4), in that the antecedent NP's ("his children", "my belief that he shouldn't") are not indefinite. This is, I believe, largely orthogonal to the issues being considered here, and reflects the general issue of *accommodation*. In each case, the NP clearly *does* become available as an antecedent for a subsequent pronoun; thus, a modification to DPL is required, permitting definite NP's to modify the output assignment function, in certain cases.

Sag/Williams lambda abstraction approach. I point out some problems with this approach, and then consider two approaches that present solutions to some of these problems. I point out important differences between the proposed approach and these semantic alternatives.

7.1 The Lambda Abstraction Approach

I begin with the lambda abstraction approach to VP anaphora, as proposed by Sag (1976) and Williams (1977). The essential point of the lambda abstraction approach is that the antecedent VP is represented as a lambda abstract. Consider the following example:

(8) Susan **loves her cat**, and Jane does $[_{VP}$] too.

Here the antecedent VP is represented as follows:

λ x.x loves x's cat

This representation can be applied to both *Susan* and *Jane*, allowing the sloppy reading while retaining a semantic identity condition on VP ellipsis. The lambda abstraction approach relies on two rules. The first rule is the Derived VP rule (Partee 1975), which allows VP's to be represented as lambda abstracts. Second, the Pronoun Rule allows a subject-coreferent pronoun to be replaced with a λ-bound variable. These rules are defined as follows:

Derived VP Rule: VP $\Rightarrow$ λ x.x VP

Pronoun Rule: λ x.x ... he ... $\Rightarrow$ λ x.x ... x ...

With these rules, together with a **VP Copy** rule which copies a VP to an ellipsis site[13], the derivation of (6) proceeds as follows:

Susan_1 $[_{VP}$ loves her_1 cat]. Jane_2 does too.

DVP

Susan_1, $[_{VP}$ λ x.x loves her_1 cat]. Jane_2 does too.

Pronoun Rule

Susan_1, $[_{VP}$ λ x.x loves x's cat]. Jane_2 does too.

VP Copy

Susan_1, $[_{VP}$ λ x.x loves x's cat]. Jane_2 does $[_{VP}$ λ x.x loves x's cat] too.

The above derivation corresponds to the sloppy reading. Without application of the Pronoun Rule, the strict reading is derived.

[13]Sag uses a VP deletion rule instead of a VP copy rule.

The lambda abstraction approach imposes a basic constraint on sloppy identity in VP anaphora, termed the *Alphabetic variance condition*, which is stated as follows:

> a variable bound outside the antecedent VP must be bound by the same binder in the ellipsis site.[14]

Thus, a sloppy variable in VP anaphora must be λ-bound within the antecedent VP. The above derivation is consistent with this, since the sloppy variable x is λ-bound in the antecedent VP.

Two immediate consequences of the lambda abstraction approach are the following:

1. there can be only one sloppy variable in VP anaphora
2. sloppy identity in VP anaphora is subject covariance

Both of these restrictions are violated. First, there are cases of VP anaphora with more than one sloppy variable, as shown by the following example:

(9) The person who introduced Mary$_i$ to John$_j$ would not **give her$_i$ his$_j$ phone number**, nor would the person who introduced Sue to Bill. (Wescoat 1989)

Here, we have two sloppy variables, her$_i$ and his$_j$.

The second restriction can also be violated; that is sloppy variables need not covary with subjects. This is shown by the following examples[15]:

(10) If Tom$_i$ was having trouble in school, I would **help him$_i$**.
On the other hand, if Harry$_j$ was having trouble, I doubt that I would. [help him$_j$]

(11) Every boy$_i$ in Bill's class hoped Mary would **ask him$_i$ out**, but every boy$_j$ in John's class hoped that she wouldn't. [ask him$_j$ out]

(12) Every boy$_i$ hopes the teacher will **like his$_i$ work**, and in Bill$_j$'s case, I'm sure she will. [like his$_j$ work]

(13) A: Speaking of Mary$_i$, John **went out with her$_i$**.
B: Really – I'm surprised that any girl$_j$ would want him to. [go out with her$_j$]

[14] This is often termed alpha-equivalence in the lambda calculus. See Hindley and Seldin (1986) for definition and discussion.

[15] The indexing given in these examples is for the purposes of indicating the intended reading only. In the proposed system, the controllers would be coindexed, and the index of the sloppy variable would not change.

In sum, the lambda abstraction approach is too restrictive in its account of sloppy identity in VP anaphora (category (1) in the above list of sloppy identity patterns); more than one sloppy variable is possible, and sloppy identity cannot be restricted to subject-covariance. Furthermore, it is not clear how to generalize the lambda abstraction approach to cover the other three patterns of sloppy identity.[16]

7.2 The Equational Approach

The Equational Approach (Dalrymple et al. 1991) retains the lambda abstraction mechanism of the Sag/Williams approach, although it applies in a much more flexible manner. In the Equational Approach, ellipsis is resolved by solving an equation for a variable which represents the elided material. Consider the following example:

(14) John **walked**. Tom did too.

To resolve the ellipsis, the following equation must be solved:

(15) P(John) = walked(John)

In other words, what property P *could have been* applied to *John* to result in the complete proposition, *walked(John)*? Solutions to the equation represent possible antecedents for the elliptical VP. In this example, with appropriate restrictions on the form of solutions,[17] there is only one solution:

λ x.walk(x)

More generally,Dalrymple et al. state the ellipsis problem as one of finding solutions to the equation

$$P(s_1,s_2,\ldots,s_n) = s$$

where P is an n-place relation, and $s_1,s_2,\ldots,s_n$ are "parallel elements".[18] The value of P is then used as the interpretation of the elided material, as follows:

$$P(t_1,t_2,\ldots,t_n)$$

[16] Webber (1978) presents a range of counter-examples to the lambda abstraction approach. These counter-examples are discussed further in Hardt (1993).

[17] Dalrymple et al. (page 6) require abstraction over "primary occurrences". This rules out λ x.*walk(John)*, which would otherwise be a possible solution.

[18] In VP ellipsis, there will typically be one parallel element: the subject. However, the Equational Approach is not restricted to VP ellipsis, but is meant to apply to a broad range of elliptical phenomena, including cases such as gapping where there are generally two parallel elements.

Here, t_1 through t_n are the corresponding parallel elements in the clause containing the ellipsis.

Just as in the Sag/Williams account, sloppy identity is explained by the lambda abstraction mechanism; a pronoun receives a sloppy reading only if it is represented as a λ-bound variable. Thus it would appear that the Equational Approach would fail to permit sloppy identity in examples (10)-(13), since the sloppy variable is not λ-bound in the antecedent. On the other hand, Dalrymple et al. do present a solution to another problem I pointed out concerning the lambda abstraction approach: the restriction to a single sloppy variable. Dalrymple et al. present a derivation of the example (9), in which there are two sloppy variables. The derivation begins with the following equation:

$$\mathrm{P(pwi(m,j),m,j) = refuse(pwi(m,j),give(m,phone(j)))}$$

Note that the variable is a three-place relation, despite the fact that it is associated with VP anaphora. Solving for P results in the following semantic object:

$$\lambda\ \mathrm{x}.\lambda\ \mathrm{y}.\lambda\ \mathrm{z.refuse(x,give(y,phone(z)))}$$

For the Equational Approach, it is necessary to translate the elided VP as a three-place relation because, as in the Sag/Williams approach, each sloppy variable must be λ-abstracted. This reflects a mismatch between syntactic objects and semantic types. In principle, there appears to no bound on the number of sloppy variables in VP ellipsis. For example, the following adds an additional sloppy pronoun to (9):

(16) The person who introduced Mary$_i$ to John$_j$ for the matchmaker$_k$ would not give her$_i$ his$_j$ phone number for him$_k$, nor would the person who introduced Sue to Bill for the mayor.

For the Equational Approach, this would require a four-place relation:

$$\lambda\ \mathrm{w}.\ \lambda\ \mathrm{x}.\lambda\ \mathrm{y}.\lambda\ \mathrm{z.refuse(w,for(give(x,phone(y)),z))}$$

Thus, unlike the lambda abstraction approach, the Equational Approach is not restricted to a single sloppy variable in VP anaphora. However, in solving this problem, it seems to permit an unbounded number of semantic types for VP ellipsis, making it impossible to associate an elided VP with a single semantic type, or even a limited set of possible types. In contrast to this, the proposed approach treats all elided VP's as property variables, or, more precisely, variables denoting functions from assignments to properties.

The Equational Approach is not restricted to VP ellipsis, but is meant to apply to a broad range of elliptical phenomena, including cases such as gapping, stripping, and comparative deletion. In all these cases, the elided material is recovered by the general unification method for solving the equation. This differs sharply from the proposed approach, in which VP ellipsis is treated uniformly with pronominal anaphora. This uniformity makes it possible to capture the four different categories of sloppy identity given above; it is not clear how these four categories could be captured in the Equational Approach, unless the approach was extended to cases of pronominal anaphora as well.

7.3 The Variable-Free Approach

The variable-free approach of Jacobson (1992) improves on the lambda abstraction approach in important ways. It does not require sloppy identity to be subject covariance; nor is it is limited to a single sloppy variable. Furthermore, the mechanisms applied to sloppy identity in VP anaphora have also been applied to paycheck pronoun cases (category (2) in the list of sloppy identity patterns). However, this approach has not been applied to categories (3) and (4).

In Jacobson's approach, the semantic representation language uses no variables; a pronoun is simply translated as an identity function on individuals. Consider the following example (Jacobson's (37)):

(17) Tom$_i$ wanted Sue to water his plants, while John wanted Mary to.

This example violates the lambda abstraction approach, because the sloppy pronoun "his" is not λ-bound in the antecedent VP, "water his plants". For Jacobson, the meaning of the antecedent VP is $\lambda x[water'(plants - of'(x))]$. A type-shifting mechanism is defined, permitting the pronoun position to ultimately become bound by the matrix subject, *Tom.* To resolve the elliptical VP, it is assumed that the antecedent VP meaning, $\lambda x[water'(plants - of'(x))]$, is recovered at the ellipsis site. The interpretation then proceeds in the same fashion as in the antecedent sentence; the pronoun becomes bound by the matrix subject *John.* Alternatively, a pronoun's position can become bound to some contextually salient individual, although the mechanism for this is not specified.

For VP anaphora, Jacobson's approach permits considerable flexibility in sloppy readings for a pronoun in the VP antecedent; in this respect, it is similar to the proposed approach. However, there are several important differences: first, Jacobson's approach is not dynamic. The mechanism by which a pronoun receives an antecedent in a preceding sentence is left unspecified, as is the mechanism by which a VP antecedent is recovered. In the proposed system, both pronoun and VP anaphora resolution are accomplished by a single, explicit mechanism – dynamic existential quantification. Secondly, the proposed system treats VP anaphora and pronominal anaphora uniformly as variables. It is this uniformity that makes it possible to capture the four categories of sloppy identity. It is difficult to say whether Jacobson's approach reflects a similar uniformity, since Jacobson does not give a semantic characterization of the elliptical VP. One way of giving a uniform treatment in Jacobson's approach would make an elliptical VP a constant function on properties, just as a pronoun is a constant function on individuals. Finally, the proposed approach imposes a basic constraint on sloppy identity: the Contrastive Parallelism Constraint. This states that a sloppy variable must covary with two contrastively focused controllers. Jacobson's approach does not impose such a constraint.

8 Dynamically Bound Variables in Programming Languages

The behavior of variables in the proposed system is reminiscent of that of dynamically bound variables in programming languages. With dynamic scope, a free variable in a lambda expression can be "captured" by different binders at different points in program execution. This is not permitted with static scope, which is the standard variable binding discipline. With static scope, a variable is bound by the lexically nearest binder, and it cannot be captured by another binder during program execution.[19]

With dynamic scope, the rule of α - equivalence fails: that is, λ-expressions differing only in the names of bound variables can give rise to different program behavior, just as the Sag/Williams Alphabetic Variance Condition is violated in Natural Language. Dynamic scoping can lead to programming errors, involving unintended capture of a free variable by different binders. To avoid this, the programmer can impose a *Novelty Condition*, making sure that each new binder uses a new variable name.

On the other hand, dynamic scope allows more flexibility in defining abstractions in programs, because a dynamically bound variable can act as an *implicit parameter*. To achieve this, the programmer intentionally violates the Novelty Condition.

Consider the following example:[20]

Assume the following **sum** and **product** functions:

(sum f a b) $\Rightarrow$ f(a) + f(a+1) ... + f(b-1) + f(b)
(product f a b) $\Rightarrow$ f(a) * f(a+1) ... * f(b-1) * f(b)

Now, we can use **sum** and **product** to define **sum-powers** and **product-powers**, as follows:

```
(define (sum-powers a b n) (sum nth-power a b))
```

[19] For definitions and examples see any standard text on programming languages, eg, Sethi 1989, pages 407-408.

[20] This example is modified from Abelson and Sussman 1985, pages 321-323.

```
(define (product-powers a b n) (product nth-power a b))

(define (nth-power x) (expt x n))
```

From these definitions, we have:
(sum-powers a b n) ⇒ $a^n + (a+1)^n \ldots (b-1)^n + b^n$
(product-powers a b n) ⇒ $a^n * (a+1)^n \ldots (b-1)^n * b^n$

Dynamic scope makes it possible for the variable n to act as an *implicit parameter* for the **nth-power** function. n is akin to a sloppy variable in Natural Language, since it is not λ-bound in **nth-power**, but it can "switch" from one controller to another. With static scope, this would not be possible, and the above functions could not be defined as concisely. Natural Language exhibits a similar flexibility in defining abstractions. [21]

9 Some Related Issues

One potential problem with the proposed approach is that the first controller in a sloppy identity configuration becomes inaccessible in subsequent discourse, since the second controller re-uses the same index. Thus in example (7), repeated below, *John* would be inaccessible to subsequent anaphoric reference.

(7) John **saw his cat**. Bill did too.

It is not clear whether this is a problem, since a subsequent occurrence of a pronoun "he" referring to *John* is not, to my ear, particularly felicitous. One suspects, however, that an acceptable discourse of this sort could be constructed. If so, the mechanism of simply eliminating the first controller would have to be modified. Furthermore, consider the following example:

(18) John **saw his cat**. Another man did too.

Here, the interpretation of "another" is "distinct from John". It is difficult to see how to express this in the current system, since the occurrence of "another" makes *John* inaccessible.[22] In future work, I will explore a modification of the approach described here, in which the value of the previous controller is moved to a different index in the assignment function, rather than eliminated.

[21] Frances and vanEijk (1993) make a similar suggestion for a dynamic scoping mechanism for sloppy identity, although the approach differs in important respects from the one described here. First, Frances and van Eijk's approach to scoping disciplines is "mixed", that is, some variables are dynamic, while others are statically scoped. Furthermore, Frances and van Eijk do not treat VP anaphora and pronominal anaphora uniformly, and although they make reference to DPL, they do not give a mechanism for adding VP-meanings to an assignment function. Finally, there is no relation between sloppy identity and contrastive focus.

[22] This point is due to Hans Kamp, p.c.

I will also explore the application of the proposed approach to a broader range of phenomena. For example, it appears that the proposed approach would apply equally well to similar sloppy identity phenomena that have been observed with destressed material. Tancredi (1992) points out a similarity between ellipis and destressing with respect to sloppy identity:

(19) John said he is a genius because Bill did.

(20) John said he is a genius because Bill said he's intelligent.

In both cases, there is a possibility for a sloppy reading, where *Bill* made a claim about *Bill* (rather than *John*). As Tancredi's example shows, this is true even when the destressed material is not identical with its antecedent. There appears to be a similar restriction on sloppy readings in each case, however. In the proposed system, one could capture this generalization simply by not permitting indices to change in background material. Thus, for "he" to receive a sloppy reading in (20) there would have to be contrastive focus between "Bill" and "John", because this would mean that "Bill" re-uses the index used by "John".

10 Conclusion

Dynamic semantics represents a major extension to semantic theory, making it possible to relate objects across sentence boundaries. However, this relation has been restricted to NP's sharing identical referents. In this paper, I have extended dynamic semantics to anaphorically relate VP's as well as NP's, using the existing mechanisms of dynamic existential quantification and conjunction. Also, I have extended dynamic semantics to include identity of sense as well as identity of reference. The resulting system gives a uniform treatment of NP and VP anaphora, bringing to light a new generalization concerning four different categories of sloppy identity. In addition, the expanded domain of the dynamic framework makes it possible to state a general constraint on sloppy identity: it can only occur as covariance between contrastively focused controllers.

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