# Towards a feature-based semantics of ASL loci

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**Abstract.** American Sign Language famously disambiguates pronoun antecedents with the use of space. In ASL, NPs can be signed at different locations ('loci') in the signing space; pronouns later retrieve these NPs by pointing at the same locus. Many analyses of ASL pronouns assume that these spatial loci are the overt realization of formal variables (Lillo-Martin and Klima 1990, a.o.), based on the observations that there are arbitrarily many loci and that pronominal ambiguity can be resolved under multiple levels of embedding. In this paper, I argue that loci should *not* be analyzed as variables, but rather as morphosyntactic features. These results directly bear on the theory of Variable-Free Semantics (Jacobson 1999). A feature-based fragment is provided.

**Keywords:** American Sign Language, loci, pronouns, variables, features, variable-free semantics.

## 1. Introduction

American Sign Language famously disambiguates pronoun antecedents with the use of space. In ASL, both referential and quantificational noun phrases (NPs like *Bill* or *every boy*) can be signed at different locations ('loci') in the signing space. Pronouns can later retrieve these NPs by pointing at the same locus. For example, (1) is disambiguated depending on whether the pronoun (IX) points at the locus of JOHN or the locus of BILL. (In my transcriptions of ASL, different subscripts indicate different locations in the signing space.)

(1) $^{7}$ JOHN$_{\text{a}}$ WANT BILL$_{\text{b}}$ THINK IX-$a$ LIKE IX-$b$.

a. $=$ 'John$_a$ wants Bill$_b$ to think that he$_a$ likes him$_b$.'

b. $\neq$ 'John$_a$ wants Bill$_b$ to think that he$_b$ likes him$_a$.'

Many analyses of ASL pronouns assume that these spatial loci are the overt realization of formal variables (Lillo-Martin & Klima 1990, a.o.). This assumption arises from the observation that there are arbitrarily many loci and that pronoun ambiguity can be resolved under multiple levels of embedding, mirroring the use of indices in formal systems.

Here, I argue that loci should not be analyzed as variables, but rather as morphosyntactic features (as in, e.g., Neidle et al. 2000). In Section 3, I show that the variable-based analysis *under-generates*. Specifically, I present cases in which two loci-sharing pronouns appear free in the same expression, but nevertheless receive different interpretations. The variable-based analysis incorrectly predicts variable capture. I suggest that this favors a system in which feature mismatch can

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prevent pronoun binding, but where syntactically independent choices can't force two pronouns to co-refer. On the other hand, I show that loci share certain important properties with morphosyntactic features: (a) they may remain uninterpreted in certain environments (specifically, in ellipsis and under focus sensitive operators), (b) they induce verbal agreement, and (c) they display patterns of underspecification.

These results directly bear on the theory of Variable-Free Semantics (Jacobson 1999), which posits that the logic underlying natural language does not make use of formal variables. In Section 5, I provide a constructive proof that ASL loci can be captured in a variable-free framework: I present an explicit fragment (using Combinatory Categorial Grammar) in which loci are analyzed as a spatial feature that subdivides the syntactic category NP.

### 1.1. Methodology and Transcription Convention

All data were gathered following the 'playback method' (Schlenker 2011). A Deaf native signer was asked to sign a paradigm of sentences for a video recording. The resulting video was then played back for the same signer, who gave grammaticality judgements using a 7 point scale (7 is perfectly grammatical) and answers to any interpretation questions. Judgements could then be repeated on separate days or with different signers. In this paper, I adopt the following notational convention: ratings of 1-4 receive a '*' to indicate ungrammaticality, ratings of 5-7 receive no star; I then specify the average numerical judgement in a superscript.

Following standard convention, signs are glossed with their English translation in all capitals. Subscripts on signs represent different locations in the horizontal plane in front of the signer; in any given sentence, alphabetical order of subscripts indicates right-to-left placement of loci. A subscript $i$ on a noun indicates that the noun was signed at location $i$. A subscript before or after a verb (e.g. ${}_{a}\text{GIVE}_{b}$) indicates that the verb moves in space from or to that locus, respectively. Three pronominals are discussed. IX-$i$ (short for 'index') is a pronoun ('he, she'), signed by pointing at locus $i$. POSS-$i$ is the possessive pronoun ('his, her'), signed by directing a B-handshape (flat hand with fingers together) at locus $i$. SELF-$i$ is the reflexive pronoun ('himself, herself'), signed by directing an A-handshape (fist with thumb sticking out) at locus $i$.

## 2. Background

In American Sign Language, NPs may be associated with locations ('loci'). Pronouns refer back to these NPs by literally pointing at the relevant locus. For example, the sentence in (2) is disambiguated depending on whether the pronoun points back to the locus established by the first or the second NP (shown in (3a) and (3b)). These loci can be placed at arbitrary locations in the horizontal plane in front of the signer (modulo some pragmatic restrictions, to be discussed), and there can be arbitrarily many loci, up to the limitations of memory.

(2) $^7$ IX-$a$ JOHN$_a$ TELL IX-$b$ BILL$_b$ {IX-$a$/IX-$b$} WILL WIN.
'John$_i$ told Bill$_j$ that he$_{\{i/j\}}$ would win.'

(3)

a. 

IX-$a$

b. 

IX-$b$

These pronominal signs in ASL are not only referential. In particular, pronouns can undergo true quantificational binding: in (4) and (5), the meaning of the pronouns co-varies with the quantifier.

(4) $^7$ [ALL BOY]$_a$ WANT [ALL GIRL]$_b$ THINK {IX-$a$/IX-$b$} LIKE {IX-$b$/IX-$a$}.
'Every boy wants every girl to think that {he/she} likes {her/him}.'

(5) $^7$ [NO BOY]$_a$ WANT [ANY GIRL]$_b$ THINK {IX-$a$/IX-$b$} LIKE {IX-$b$/IX-$a$}.
'No boy wants any girl to think that {he/she} likes {her/him}.'

Further, loci may even be used to disambiguate quantificational antecedents that have the same domain of quantification. For example, sentence (6) has a reading in which both indefinites range over the same set of individuals (truth-conditionally evident because they scope under another operator); as above, however, the sentence is disambiguated by the use of loci.

(6) $^7$ WHEN SOMEONE$_a$ HELP SOMEONE$_b$, IX-$b$ HAPPY.
'When someone helps someone, the latter is happy.'

Taking these examples together, there is a striking parallel between loci and formal variables; indeed, even the English glosses in much of this paper use variables as subscripts! It is this observation that motivates Lillo-Martin and Klima (1990) and others to propose that, in fact, variables are the overt phonological manifestation of variable names.

## 3. Variables or Features?

In this paper, I compare two possible avenues of analysis. The first option, following Lillo-Martin & Klima 1990, is to hypothesize that loci are in direct correspondence with formal variables. The second option is to hypothesize that loci are in fact some kind of morphosyntactic feature, which is manipulated by the same syntactic mechanisms which govern canonical features (gender, number, person) elsewhere in language. This latter option is chosen by Neidle et al. 2000, although we note that they do not give an explicit formalization.

The two hypotheses are presented formally in the following:

(7) **The (strong) loci-as-variables hypothesis:** There is a one-to-one correspondence between ASL loci and formal variables.

(8) **The loci-as-features hypothesis:** Different loci correspond to different values of some morphosyntactic spatial feature.

In the following sections, I distinguish properties and test predictions of the two hypotheses. We find that the feature-based analysis allows a larger set of interpretations and grammatical sentences than the variable-based analysis: specifically, only the feature-based analysis allows two individuals to be indexed at the same locus. I show that these examples are attested, and that the variable-based analysis undergenerates.

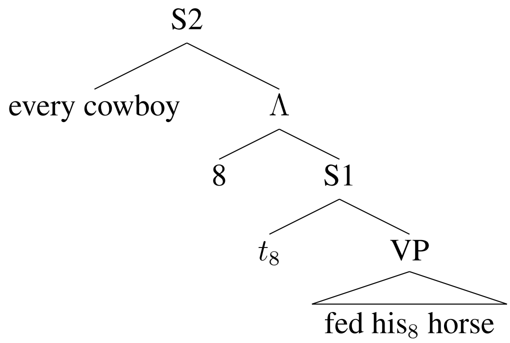
### 3.1. Binding with variables

What is a variable? Linguists have employed variables to describe natural language, but the concept is a more basic, logical notion. Conceptually, a variable is characterized by its relation with other variables: critically, two variables of the same name are semantically tethered, and must receive the same value. In the lambda calculus, for example, this property arises from the definition of variable substitution; specifically, a recursive syntactic definition ensures that all instances of a given variable are replaced by the substituted term. (For a detailed exposition of this point and the finer details of the lambda calculus, see Barker ms.)

In natural language semantics, the semantic tethering of variables is traditionally accomplished through the use of **assignment functions** (Heim & Kratzer, 1998, p. 111), which map each free variable (taken to be the natural numbers 1, 2, 3, ...) to an individual (John, Mary, ...). Critically, assignment functions are *functions* (i.e. each input is related to exactly one output), so all occurrences of a given free variable are mapped to the same individual.

Within these theories, variable binding is accomplished by manipulating the assignment functions: if S1 is a sentence with a free variable 8, the value of $[\![8\ \text{S1}]\!]^g$ is a function that takes an individual $x$ and returns $[\![\text{S1}]\!]^{g'}$, where $g'$ is identical to $g$ but with 8 mapping to $x$. Examples (9) and (10) provide an example.

(9)




(10) a. $[\![\text{S1}]\!] = \lambda g[g(8)$ fed $g(8)$'s horse$]$
b. $[\![\text{8 S1}]\!] = \lambda g \lambda x [\![\text{S1}]\!]^{g^{8 \to x}} = \lambda g \lambda x[x$ fed $x$'s horse$]$

Importantly, this system has the property of **variable capture**: a variable is bound by the lowest operator which scopes over it and quantifies over that variable. As a correlate: if two occurrences of the same variable are free in some sub-expression, they will both be captured by the same operator.

### 3.2. Variable-Free Semantics

A second theory of pronominal binding is the framework of Variable-Free Semantics (VFS: Jacobson 1999), a model of natural language semantics in which the denotation of every constituent can be expressed as a term with no free variables. In VFS, pronouns denote the identity function over individuals, as in (11). The argument slot introduced by the pronoun can then be passed through the syntax via function composition, using the 'Geach' operator in (12). Finally, binding is accomplished using Jacobson's z-combinator, which merges two argument slots (shown in (13)).

(11) *he* = $\langle \text{NP}^{\text{NP}}, \lambda x.x \rangle$

(12) *Syntactic and semantic definitions of function composition via Geach (**g**):*
a. $\mathbf{g}'$(A/B) = $\text{A}^{\text{NP}}/\text{B}^{\text{NP}}$
b. $\mathbf{g}(f) = \lambda h \lambda y[f(h(y))]$

(13) *Syntactic and semantic definitions of binding (**z**):*
a. **z**((B/NP)/A) = (B/NP)/$\text{A}^{\text{NP}}$
b. $\mathbf{z}(V_{\langle \alpha, \langle e, \beta \rangle \rangle}) = \lambda f_{\langle e, \alpha \rangle} \lambda x_e [V(f(x))(x)]$

Examples (14) and (15) demonstrate how **g** and **z** interact in the grammar to achieve binding. In (14), the **g** combinator passes up the individual argument slot; because this pronoun is never bound, the (extensional) meaning of the sentence is a function from individuals to truth values. In (15), the **z** combinator acts on the verb, merging the $e$-type argument of the *mother-of* function with the second $e$-type argument of *loves*. The extension of the sentence is a truth value.

(14) "He laughed." = $\mathbf{g}(\text{laughed}')(\text{he}')$ = $\langle \text{S}^{\text{NP}}$ , $\lambda y_e.\text{laughed}'(y) \rangle$

(15) "John loves his mother"

a. **z**-loves′ = ⟨ $(S/NP)/NP^{NP}$ , $\lambda f x.\text{loves}'(f(x))(x)$ ⟩
b. **z**-loves′(his-mother′) = ⟨ (S/NP) , $\lambda x.\text{loves}'(\text{mother-of}'(x))(x)$ ⟩
c. **z**-loves′(his-mother′)(John′) = ⟨ S , $\text{loves}'(\text{mother-of}'(j))(j)$ ⟩

Logically, both variable-full and variable-free systems have the same expressive power (for example, the lambda calculus can be translated into Combinatory Logic, which does not make use of variables). Thus, the theoretical question is not whether one or the other is *able* to express a certain meaning (both can), but rather, how well each framework fits into a believable syntactic model.

One argument against variables is the observation that indices have no phonological manifestation in spoken language — we do not pronounce "$\text{he}_x$" and "$\text{he}_y$" differently. As we have seen, however, American Sign Language has been argued to be a counter-example to this generalization. Thus, if loci did indeed show all the properties of formal variables, this would be a strong argument against the Variable-Free hypothesis.

### 3.3. Evidence against variables: no accidental variable capture

As we saw in Section 3.1, variables have the property that two occurrences of the same variable must refer to the same individual. Features do not have this property. If two NPs have different features, they are *not* able to be co-referent (thus, ambiguity can be eliminated in some cases); however, if two NPs have the same feature, they are not *forced* to denote the same individual. For example, the gender features on *he* and *she* in (16) prevent the pronouns from referring to the same individual. However, although both pronouns in (17) bear identical features, they nevertheless can refer to different individuals.

(16) John told Mary that he thinks she will win.
→*'He' and 'she' cannot pick out the same individual.*

(17) John told Barry that he thinks he will win.
→ *The two occurrences of 'he' need not pick out the same individual.*

This is therefore a property which distinguishes the two analyses. In this section, we observe that loci do *not* force co-reference, thus falsifying the strong loci-as-variables hypothesis.

#### 3.3.1. Loci indexing more than one individual

As discussed, the variable-based analysis employs assignment functions, which, by definition, map each variable to exactly one individual. On the hypothesis that there is a one-to-one relation between variables and loci, the variable-based analysis therefore predicts that a given locus can only index one individual at a time. Sentence (18) provides a counter-example to this prediction. Here, Both JOHN and MARY are signed at locus $a$, so IX-$a$ can retrieve either individual. Likewise, both BILL and SUZY are signed at locus $b$.

(18) [6] EVERY-DAY, $\text{JOHN}_\text{a}$ TELL $\text{MARY}_\text{a}$ IX-$a$ LOVE IX-$a$. $\text{BILL}_\text{b}$ NEVER TELL $\text{SUZY}_\text{b}$ IX-$b$ LOVE IX-$b$.
'Every day, $\text{John}_i$ tells $\text{Mary}_j$ that $\text{he}_i$ loves $\text{her}_j$. $\text{Bill}_k$ never tells $\text{Suzy}_l$ that $\text{he}_k$ loves $\text{her}_l$.'

In contrast, the grammaticality of (18) comes automatically under the agreement analysis, in which a NP may bind any pronoun that agrees in locus.

A possible counter-analysis is that JOHN and MARY are *not* actually indexed at the same locus, but rather that they are indexed at two loci which are so close together that they are phonetically indistinguishable. However, evidence against this analysis comes from both production and reception. In production, the signer was asked explicitly to place the pairs of people at the same locus; the sentence above is what was produced. In reception, the sentence was judged as technically ambiguous, but with one very implausible reading (in which John tells Mary her own opinions.)

Nevertheless, in most contexts, it still seems to be the case that indexing two individuals at the same locus is dispreferred. This dispreference, as well as the relative acceptability of (18), can be explained in pragmatic terms. First, there is a general pragmatic pressure to avoid ambiguity. (In fact, Grice 1975 posits this as an explicit maxim in the Manner category.) In ASL, one way to accomplish this end is through the use of multiple loci. However, in the example above, this pragmatic pressure is reduced by other means: two logically-possible readings are ruled out by binding theory (Condition B), and the final reading is ruled out by implausibility.

This analysis is supported by the observation that sentence judgements decrease when ambiguity increases. For example, (19) is parallel to (18) except that Condition B no longer eliminates readings. In a paired paradigm, (18) receives a rating of 6/7; (19) receives a rating of 4/7.

(19) * [4] EVERY-DAY, $\text{JOHN}_a$ TELL $\text{MARY}_a$ IX-$a$ THINK IX-$a$ SMART. $\text{BILL}_b$ NEVER TELL $\text{SUZY}_b$ IX-$b$ THINK IX-$b$ SMART.
'Every day, John tells Mary that he thinks {he/she} is smart. Bill never tells Susan that he thinks {he/she} is smart.

In short, in certain specific examples where pragmatic effects are controlled for, it appears that ASL loci *can*, in fact, be indexed at the same locus. The variable-based analysis gets the wrong prediction.

### 3.3.2. Uninterpreted loci under *only*

In spoken language, pronouns under *only* are known to optionally co-vary in the focus alternatives, depending on whether the pronoun is bound by the lambda operator or free and co-referential with the referential NP.

(20) a. [Only Mary$_x$] $\lambda y.y$ did her$_x$ homework. *(John didn't do Mary's homework.)*
b. [Only Mary$_x$] $\lambda y.y$ did her$_y$ homework. *(John didn't do his own homework.)*

Further, Kratzer (2009) observes that when two pronouns appear under *only*, there are four possible readings, including two mixed readings, with one pronoun bound and one free. The two mixed readings for the sentence in (21) are shown in (22) with disambiguating contexts.

(21) Only Billy told his mother his favorite color.

(22) a. [Only Billy$_x$] $\lambda y.y$ told $y$'s mother $x$'s favorite color.
*Context:* In class on Friday, Sally learned that Billy's favorite color is pink, and, to his horror, soon told everybody else in the class. Later, Billy told his mother the situation, and said he was worried that the children would spread the gossip to their mothers. It turns out that Billy had nothing to worry about.
b. [Only Billy$_x$] $\lambda y.y$ told $x$'s mother $y$'s favorite color.
*Context:* Billy's mother can be very embarrassing sometimes. When she has his friends over to play, she asks them all sorts of personal questions, which they are usually reluctant to answer. Yesterday, she asked them what their favorite color is, but only Billy answered.

But, if ASL loci are variables, then the use of loci should make these mixed readings unavailable. In particular, when two spatially co-indexed pronouns appear under *only* (as in (23)), both are predicted to give the same (bound or free) reading, since both of them — denoting the same variable — must be captured by the same operator. However, mixed readings *are* attested.

(23) [7] IX-$a$ JESSICA TOLD-ME IX-$b$ BILLY ONLY-ONE FINISH-TELL POSS-$b$ MOTHER POSS-$b$ FAVORITE COLOR.
'Jessica told me that only Billy told his mother his favorite color.'
***Can be read as:*** *bound-bound, bound-free, free-bound, or free-free.*

To capture these data, the variable-based analysis would need to sacrifice the strong hypothesis in which loci directly correspond with variables[1].

On the feature based analysis, the example in (23) displays a striking similarity to the phenomenon of **uninterpreted features** in spoken language. Specifically, Kratzer 2009 observes that under

[1] A possible alternative way out for the strong variable hypothesis is to reject the assumption that all readings arise from the Logical Form. For example, in Fox's (2000) analysis of ellipsis, elided pronouns may get a bound reading from the Logical Form ("structural parallelism") but may also receive a free reading through "referential parallelism." We note, however, that Fox's analysis of ellipsis fundamentally does not translate over to the *only* examples discussed here.

focus sensitive operators (like *only*), features are not interpreted in the focus alternatives. For example, both sentences in (24) have a bound and free reading. Critically, on the bound reading, (24a) entails that John didn't do his homework, even though he is not a female; (24b) entails that John didn't do his homework, even if he is not the speaker.

(24) a. Only Mary did her homework.
b. Only I did my homework.

Sentence (23) is exactly parallel: the pronouns bear a spatial feature which is uninterpreted in the focus alternatives. So, for example, the bound-bound reading of (23) entails that Jessica didn't tell her mother her favorite color, even though Jessica (at locus $a$) bears a different spatial feature from Billy (at locus $b$).

Thus, the readings in (23) pose no problem for a feature-based analysis. Either pronoun may be bound or free; in both cases, it must agree with the same locus. The spatial feature in bound readings is uninterpreted, just as the gender and person features in (24) are uninterpreted.

### 3.4. Parallels with features

In the previous section, I gave evidence against a variable-based analysis, showing that a strong form of the loci-as-variable hypothesis is not tenable under a set of standard assumptions. In this section, I approach the question from the opposite side — I show that loci share a number of important properties with features in spoken language.

Section 3.3.2 already showed one such commonality: we saw that loci, like features, may remain uninterpreted under focus-sensitive operators. Here, I discuss two further parallels: verbal agreement and underspecification. I take these examples as further evidence that an analysis of loci (whatever its final form) should be the same as an analysis of features elsewhere in language.

#### 3.4.1. Directional verbs as verbal agreement

One of the fundamental properties of morphosyntactic features — indeed, a major reason why they are interesting for theories of formal syntax — is that they are able to induce changes on verbal and adjectival morphology in the form of agreement. ASL loci, like standard morphosyntactic features, also show this property. In particular, a large class of verbs — neutrally entitled "directional verbs" — move in space from the locus of one argument to the locus of another. These directional verbs may agree with a single argument (as in (25a,b)) or both of the arguments (as in (25c,d)).

(25) a. $\text{TELL}_a$: motion starts at the chin and moves to the locus of the indirect object ($a$).
b. $\text{SEE}_a$: motion starts at the eyes and moves to the locus of the direct object ($a$).
c. ${}_a\text{HELP}_b$: motion starts at the locus of the subject ($a$) and moves to the locus of the direct object ($b$).

d. ${}_a$GIVE$_b$: motion starts at the locus of the subject ($a$) and moves to the locus of the indirect object ($b$).

Example (26) demonstrates the interaction of NP loci with directional verbs. Specifically, a sentence is only grammatical if the locus of the argument matches the locus that is activated by the agreeing verb.

(26) a. [7] BOOK, JOHN$_a$ ${}_a$GIVE$_b$ MARY$_b$. *(Match)*
b. * [3.5] BOOK, JOHN$_c$ ${}_a$GIVE$_b$ MARY$_b$. *(Mismatch)*
c. * [3.5] BOOK, JOHN$_a$ ${}_a$GIVE$_b$ MARY$_c$. *(Mismatch)*
'John gave the book to Mary.'

A lively debate has centered around the correct analysis of directional verbs. The standard view (Fischer & Gough 1978, a.o.) is that these are simply an instance of verbal agreement. On the other hand, Liddell (2000), recognizing the often iconic properties of directional verbs, proposes that directionality is ultimately non-linguistic gesture. Lillo-Martin and Meier (2011) argue against this view, pointing to examples of exceptional first-person forms, as well as a number of syntactic effects of directional verbs. I follow Lillo-Martin and Meier (and much of the rest of the literature) in considering directionality to involve a truly linguistic system.

Under a feature-based analysis, the basic data falls out as a special case of feature agreement on verbs. In contrast, a variable-based approach would need to posit a new mechanism of index agreement. For example, Aronoff et al. (2005) proposes one such analysis, in fact going so far as to suggest that all feature agreement is index copying.

So, unlike the examples in the previous section, this is not a place in which the variable-based analysis *fails* as such. Rather, it is an place where the properties of loci seem to pattern with the properties of features: features are generally able to induce agreement on verbs. Given the existence of directional verbs, loci appear to have this property.

### 3.4.2. Underspecification

Another commonality between loci and features is the phenomenon of *underspecification*. As just discussed, some verbs (or syntactic heads more generally) require their arguments to bear a specific, agreeing feature. On the other hand, verbs may also be underspecified, accepting arguments with any feature. For example, in English, agreement morphology on present tense verbs dictates the number of their subject (as in (27)). However, past tense verbs are underspecified in this respect: they can take either singular or plural subjects (as in (28)).

(27) *Sleep* and *sleeps* subcategorize for the number of the subject.

a. A boy sleeps.
b. * A boy sleep.
c. * Boys sleeps.
d. Boys sleep.

(28) *Slept* takes either a singular or plural subject.
a. A boy slept.
b. Boys slept.

Turning to ASL loci, we find that a similar property (unsurprisingly) holds here. Although some verbs are directional, many verbs are not, and are signed in a neutral location, and may take arguments at any loci. A very simple example is the predicate HAPPY, as seen in (29).

(29) HAPPY takes a subject at any locus.
a. $^{7}$ JOHN$_a$ HAPPY.
b. $^{7}$ JOHN$_b$ HAPPY.

Thus, in both verbal agreement and underspecification, we find that loci pattern with morphosyntactic features. So, although variable-based analyses could be built for both of these patterns, the patterns will fall out from independently needed technology under a feature-based analysis.

## 4. Interim summary

### 4.1. A second chance for variables.

At this point, the strong loci-as-variables hypothesis has been falsified. Specifically, in Section 3.3, we showed two cases where the theory wrongly predicts variable capture and undergenerates readings. On the other hand, modifications may be made to our assumptions to salvage a variable-based analysis. In particular, weaker forms of the hypothesis are available which do not fall subject to the same incorrect predictions. In particular, if we allow each locus to correspond with a set of more than one variable (as in (30)), then pointing to that locus does not necessitate variable capture.

(30) **A weakened variable-based hypothesis:**
Loci create *partitions* of variables; pointing to a locus retrieves one of a set of variables.

We will not discuss predictions of this hypothesis here, but it bears pointing out that this new formulation may effectively be recreating the feature-based theory in terms of variables.

It is also important to note that the arguments above do not preclude the existence of variables *in general*. That is, even if a variable-based analysis of *loci* is falsified, it doesn't mean that variables don't exist in natural language, it just means that loci aren't them.

### 4.2. Implications for theories of features

As an alternative to the variable-based analysis, I have argued that loci pattern with morpho-syntactic features, based on a number of important shared properties. On the other hand, if loci are features, then they are typologically unique in one important respect: spoken languages display a finite (if sometimes large) set of morpho-syntactic features, but the set of possible loci in ASL is theoretically infinite. Lillo-Martin and Klima (1990) stress this point, observing that although there are generally not more than a few loci used at a given time, it is always in principle possible to establish a new locus between any two existing loci.

On the other hand, the existence of infinite feature sets in sign language has been independently motivated by Schlenker (2013), approaching questions of iconicity in sign language. Schlenker shows that certain iconic properties of referents, like height and body orientation, share formal properties with morpho-syntactic features; he is led to an analysis in which features themselves bear structured iconicity. A theoretical consequence of this analysis, then, is the existence of infinitely many features in sign language, since the iconic properties dictate that there are infinitely many possible forms of these features.

Thus, although unbounded feature sets are typologically rare in spoken languages (although see Aronof et al. 2005 on 'literal alliterative agreement' in Bainouk and Arapesh), they nevertheless seem to be attested in sign languages.

### 4.3. Rescuing Variable-Free Semantics

The arguments above also carry ramifications for the theory of Variable-Free Semantics. As discussed in Section 3.2, Jacobson (1999) argues that the logic underlying natural language does not make use of formal variables, and that both free and bound pronouns can be captured through other combinatorial mechanisms. This was motivated in part by the observation that spoken language never overtly realizes the difference between two different variables. As we saw, though, the ASL data posed a potential counter-example: if indeed loci were variables (or formally isomorphic to them), then the Variable-Free hypothesis would have been falsified. Therefore, in arguing against the variable-based analysis of ASL loci, I concurrently removed what would otherwise be a fatal argument against Variable-Free Semantics.

## 5. A feature-based fragment

This section presents a fragment which implements a feature-based analysis using Combinatory Categorial Grammar. As mentioned in Section 4.1, a feature-based analysis of loci does not necessitate a fully variable-free system. Nevertheless, in order to provide a constructive proof that loci do not necessitate a variable-full semantics, the fragment presented is both variable-free and Directly Compositional (in the sense of Jacobson 2007). For exposition, I present it piece by piece through the prose of this section, but the full fragment is repeated in one place in Appendix A.

The system has one basic composition schema, implemented as two rules: composing with an argument on the right and composing with an argument on the left. These appear in (31).

(31) *Composition rules (f.a.):*

a. $\langle \text{A/}_{\text{R}}\text{B}, f\rangle \quad \langle \text{B}, x\rangle \quad \rightarrow \quad \langle \text{A}, f(x)\rangle$

b. $\langle \text{B}, x\rangle \quad \langle \text{A/}_{\text{L}}\text{B}, f\rangle \quad \rightarrow \quad \langle \text{A}, f(x)\rangle$ *(Subscripts R and L are left out below.)*

Before we come to pronouns and binding, it will be helpful to understand how loci work as features in the rest of the grammar. As in English, a proper name denotes a specific individual and is an NP. In ASL, though, NPs may be localized, bearing a spatial feature; I represent this with a subscript: an NP at locus $i$ is of category $\text{NP}_i$. For example, the lexical entry for $\text{JOHN}_a$ is $\langle \text{NP}_a, j\rangle$.

Definitions for verbs are given in (32). Agreeing verbs specify a spatial feature on one or more of their NP arguments. Thus, ${}_a\text{HELP}_b$ (which moves in space from locus $a$ to locus $b$) is of category $(\text{S/NP}_a)/\text{NP}_b$: it is a function which requires two NPs: one at locus $a$ and one at locus $b$.

(32) *Lexical entries for verbs (lex):*

a. $\text{LIKE} = \langle \ (\text{S/NP})/\text{NP} \ , \ \lambda xy.\text{like}'(x)(y) \ \rangle$

b. $\text{THINK} = \langle \ (\text{S/NP})/\text{S} \ , \ \lambda py.\text{think}'(p)(y) \ \rangle$

c. $\text{SEE}_a = \langle \ (\text{S/NP})/\text{NP}_a \ , \ \lambda xy.\text{see}'(x)(y) \ \rangle$

d. ${}_a\text{HELP}_b = \langle \ (\text{S/NP}_a)/\text{NP}_b \ , \ \lambda xy.\text{help}'(x)(y) \ \rangle$

Ungrammaticality of incorrect verbal agreement arises from subcategorization mismatch. Example (33) shows a successful derivation, in which both arguments match the argument specifications in the lexical entry of the verb. Example (34) shows an unsuccessful derivation; the predicate "${}_a\text{HELP}_b$ $\text{BILL}_b$" requires an argument of category $\text{NP}_a$, but the subject is of category $\text{NP}_c$.

(33) [7] $\text{JOHN}_a$ ${}_a\text{HELP}_b$ $\text{BILL}_b$.

$$\dfrac{\dfrac{\text{JOHN}_a}{\text{NP}_a}\,lex \qquad \dfrac{\dfrac{{}_a\text{HELP}_b}{(\text{S/NP}_a)/\text{NP}_b}\,lex \quad \dfrac{\text{BILL}_b}{\text{NP}_b}\,lex}{\text{S/NP}_a}\,f.a.}{\text{S}}\,f.a.$$

(34) * [3] $\text{JOHN}_c$ ${}_a\text{HELP}_b$ $\text{BILL}_b$.

$$\dfrac{\dfrac{\text{JOHN}_c}{\text{NP}_c}\,lex \qquad \dfrac{\dfrac{{}_a\text{HELP}_b}{(\text{S/NP}_a)/\text{NP}_b}\,lex \quad \dfrac{\text{BILL}_b}{\text{NP}_b}\,lex}{\text{S/NP}_a}\,f.a.}{\textbf{can't combine}}\,f.a.$$

## 5.1. Underspecification as subsumption

As we saw in section 3.4.2, verbs may be underspecified in ASL as in English: in English, past tense verbs take singular or plural NPs; in ASL, non-directional verbs take NPs at any locus.

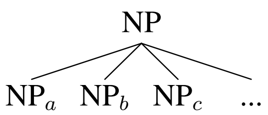
(35) a. A boy sleeps.
b. * Boys sleeps.
BUT
c. A boy slept.
d. Boys slept.

(36) a. [7] JOHN$_a$ $_a$HELP$_b$ BILL$_b$.
b. * [3] JOHN$_c$ $_a$HELP$_b$ BILL$_b$.
BUT
c. [7] JOHN$_a$ LIKE BILL$_b$.
d. [7] JOHN$_c$ LIKE BILL$_b$.

Following Bernardi and Szabolcsi (2007), we propose that syntactic categories are organized as partially ordered sets; being a satisfactory argument for a given function requires subsumption, not identity. In English, for example, they propose that NP$_{plur}$ and NP$_{sing}$ are both subsumed by the umbrella category NP. The past-tense verb *slept* is of category S/NP; thus, both singular and plural NPs serve as satisfactory arguments.

ASL loci are exactly parallel: NP subsumes NP$_i$ for all $i$. Non-directional verbs subcategorize for the umbrella category NP, so will be satisfied by any subcategory — that is, by any localized NP.

(37)




For example, the lexical entry for HAPPY is $\langle$S/NP, $\lambda x$.happy$'(x)\rangle$. Parallel to the English example above, all localized NPs serve as satisfactory arguments.

This deduction pattern can be formalized as a combinator which fills in the spatial feature on an argument slot of an underspecified verb.

(38) loc $= \langle$ ((A/NP$_i$)/B)/((A/NP)/B) , $\lambda X.X$ $\rangle$

Example (39) shows the 'loc' combinator in action; example (40) provides a derivation.

(39) a. HAPPY = S/NP $\xrightarrow{loc}$ S/NP$_a$
b. LIKE = (S/NP)/NP $\xrightarrow{loc}$ (S/NP$_b$)/NP

(40) [7] JOHN$_a$ HAPPY.

$$\dfrac{\dfrac{\text{JOHN}_a}{\text{NP}_a}\,lex \qquad \dfrac{\dfrac{\text{HAPPY}}{\text{S/NP}}\,lex}{\text{S/NP}_a}\,loc}{\text{S}}\,f.a.$$

We note that Kuhn 2013 provides a strategy for building this family of 'loc' combinators recursively from a few basic primitives.

## 5.2. Pronouns and binding

Having sorted out verb agreement and underspecification, it turns out that binding requires no further additions: the binding facts fall out "for free" from the lexicon and from a generalized definition of the **z**-operator presented in Section 3.2. In particular, it should be observed in the following exposition that the only combinator which explicitly makes reference to features is the underspecification operator. All the instances of features appearing in the **g** or **z** rules are special cases of a generalized schema.

As in Jacobson's (1999) variable-free semantics, pronouns are the identity function over individuals. In Jacobson's system, pronouns have category $\text{NP}^{\text{NP}}$, indicating that they have a gap to be filled by something of category NP. However, this gap could conceivably be of a different category. For example, in Charlow's (2008) analysis of VP ellipsis, $does_{pro}$ is of category $\text{VP}^{\text{VP}}$; for ACD, it is of category $\text{TV}^{\text{TV}}$. For ASL, I have represented the spatial feature with a subscript; accordingly, pronouns at locus $i$ are of category $\text{NP}_i^{\text{NP}_i}$. This is summarized in (41).

(41) *Lexical entries for pronouns (lex):*
a. IX-$a$ $= \langle \ \text{NP}_a^{\text{NP}_a} \ , \ \lambda x.x \ \rangle$
b. SELF-$a$ $= \langle \ \text{NP}_a^{\text{NP}_a} \ , \ \lambda x.x \ \rangle$

As before, when a pronoun is free, it is passed through the system using function composition (in the form of **g**). The syntax preserves the featural information of the gap, passing along subscripts.

(42) *Syntactic and semantic definitions of function composition via Geach (**g**):*
a. $\mathbf{g}'(\text{A/B}) = \text{A}^{\text{C}}/\text{B}^{\text{C}}$
b. $\mathbf{g}(f) = \lambda h \lambda y[f(h(y))]$

(43) *Special case — Passing through the gap of a localized NP:*
a. $\mathbf{g}'(\text{A/B}) = \text{A}^{\text{NP}_i}/\text{B}^{\text{NP}_i}$

Binding is accomplished using Jacobson's z-combinator, which merges two argument slots. Critically, the syntactic definition requires the binder to be exactly the same category as the gap being bound (see (44)). Thus, when the binder has category $\text{NP}_i$, the pronoun must also be of category $\text{NP}_i$ (see (45)). In short: a pronoun and its binder must share the same locus.

(44) *Syntactic and semantic definitions of binding (**z**):*
a. $\mathbf{z}((\text{B/C})/\text{A}) = (\text{B/C})/\text{A}^{\text{C}}$
b. $\mathbf{z}(V_{\langle\alpha,\langle\gamma,\beta\rangle\rangle}) = \lambda f_{\langle\gamma,\alpha\rangle}\lambda x_\gamma[V(f(x))(x)]$

(45) *Special case — Binding a localized NP:*
a. $\mathbf{z}((\text{B/NP}_i)/\text{A}) = (\text{B/NP}_i)/\text{A}^{\text{NP}_i}$

The following two derivations demonstrate how locus agreement is achieved. Effectively, the z-combinator turns the verb phrase into an agreeing predicate; the reason why the derivation in (47) crashes is exactly the same reason why sentences are ungrammatical when there is a mismatch between a directional verb and the locus of a noun (as in (34)): the verb phrase subcategorizes for an NP with the wrong feature.

(46) [7] JOHN$_a$ LIKE SELF-$a$.

$$\dfrac{\dfrac{\text{JOHN}_a}{\text{NP}_a}\,lex \qquad \dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\,lex}{\text{(S/NP}_a\text{)/NP}}\,loc}{\text{(S/NP}_a\text{)/NP}_a}\,loc}{\text{(S/NP}_a\text{)/NP}_a^{\text{NP}_a}}\,\mathbf{z} \qquad \dfrac{\text{SELF-}a}{\text{NP}_a^{\text{NP}_a}}\,lex}{\text{S/NP}_a}\,f.a.}{\text{S}}\,f.a.$$

(47) * [2] JOHN$_b$ LIKE SELF-$a$.

$$\dfrac{\dfrac{\text{JOHN}_b}{\text{NP}_b}\,lex \qquad \dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\,lex}{\text{(S/NP}_a\text{)/NP}}\,loc}{\text{(S/NP}_a\text{)/NP}_a}\,loc}{\text{(S/NP}_a\text{)/NP}_a^{\text{NP}_a}}\,\mathbf{z} \qquad \dfrac{\text{SELF-}a}{\text{NP}_a^{\text{NP}_a}}\,lex}{\text{S/NP}_a}\,f.a.}{\textbf{can't combine}}\,f.a.$$

Essentially, the z-rule turns a predicate into an agreeing predicate: [**z**-LIKE SELF-$a$] is of the same syntactic category as [$_a$HELP$_b$ JOHN$_b$]: both are of category S/NP$_a$. The fragment thus reduces pronominal agreement to a special case of verbal agreement.

## 6. Conclusion

This paper untangled two theories of loci in American Sign Language: the first held that loci are variables; the second, that loci are morphosyntactic features. Two different cases were given in which the variable-based analysis wrongly predicted variable capture; the availability of unexpected readings thus falsified the strong loci-as-variables hypothesis. I suggested that this shows that the grammar of natural language cannot force coreference of syntactically independent constituents.

On the other hand, we saw a number of close parallels between loci and features. First, we saw that loci, like features, appear to be uninterpreted under focus-sensitive operators. Second, we saw that loci can induce verbal agreement. Third, we saw that loci seem to share the same patterns of underspecification that exist in the feature systems of spoken language.

As a constructive demonstration that variables are not necessary to analyze loci, a fragment was provided that covered all the observed facts within a variable-free system. Of note, as soon as verbal agreement facts were accounted for, the patterns of binding arose naturally from independently proposed combinators.

## Appendix A: The full fragment

(48) *Composition rules (f.a.):*

a. $\langle \text{A}/_{\text{R}}\text{B}, f\rangle \quad \langle \text{B}, x\rangle \quad \rightarrow \quad \langle \text{A}, f(x)\rangle$

b. $\langle \text{B}, x\rangle \quad \langle \text{A}/_{\text{L}}\text{B}, f\rangle \quad \rightarrow \quad \langle \text{A}, f(x)\rangle$ *(Subscripts R and L are left out below.)*

(49) *Definitions of lexical items (lex):*

a. $\text{JOHN}_a = \langle\ \text{NP}_a\ ,\ j\ \rangle$

b. $\text{IX-}a = \langle\ \text{NP}_a^{\text{NP}_a}\ ,\ \lambda x.x\ \rangle$

c. $\text{SELF-}a = \langle\ \text{NP}_a^{\text{NP}_a}\ ,\ \lambda x.x\ \rangle$

d. $\text{LIKE} = \langle\ \text{(S/NP)/NP}\ ,\ \lambda xy.\text{like}'(x)(y)\ \rangle$

e. $\text{THINK} = \langle\ \text{(S/NP)/S}\ ,\ \lambda py.\text{think}'(p)(y)\ \rangle$

f. $\text{SEE}_a = \langle\ \text{(S/NP)/NP}_a\ ,\ \lambda xy.\text{see}'(x)(y)\ \rangle$

g. $_a\text{HELP}_b = \langle\ \text{(S/NP}_a\text{)/NP}_b\ ,\ \lambda xy.\text{help}'(x)(y)\ \rangle$

(50) *Locus underspecification deductions on verbs (loc):*

a. $\text{loc} = \langle\ \text{((A/NP}_i\text{)/B)/((A/NP)/B)}\ ,\ \lambda X.X\ \rangle$

(51) *Syntactic and semantic definitions of function composition via Geach (**g**):*

a. $\mathbf{g} = \langle\ \text{(A}^{\text{C}}\text{/B}^{\text{C}}\text{)/(A/B)}\ ,\ \lambda f \lambda h \lambda y[f(h(y))]\ \rangle$

(52) *Syntactic and semantic definitions of binding (**z**):*

a. $\mathbf{z} = \langle\ \text{((B/C)/A}^{\text{C}}\text{)/((B/C)/A)}\ ,\ \lambda V_{\langle\alpha,\langle\gamma,\beta\rangle\rangle} \lambda f_{\langle\gamma,\alpha\rangle} \lambda x_\gamma [V(f(x))(x)]\ \rangle$

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