ASL Loci: Variables or Features?*

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Abstract

American Sign Language famously disambiguates pronoun antecedents with the use of space. In ASL, both referential and quantificational NPs can be signed at different locations ('loci') in the signing space. Pronouns can 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 pronoun 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. First, I show that the variable-based analysis under-generates: it is possible for two loci-sharing pronouns to appear free in the same expression but nevertheless receive different interpretations. Second, I show that loci share certain important properties with morphosyntactic features, including their behavior under focus-sensitive operators and their ability to induce complex agreement patterns. 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. As proof of concept, I provide a variable-free fragment of ASL loci.

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 the locus of JOHN or the locus of BILL. (In my transcriptions of ASL, different subscripts indicate different locations in the signing space.)

(1) JOHN_{a} WANT BILL_{b} THINK IX-a LIKE IX-b.[1]

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.

*Special thanks to Philippe Schlenker, Chris Barker, Kate Davidson, and Jonathan Lamberton for insight, patience, and support on many fronts. This paper also benefited from discussion at the NYU Semantics Group and the UConn Sign Language Group. All errors are of course my own.

[1] Although the (1b) reading is pragmatically strange, it nevertheless becomes the only reading when the indexing is reversed.

On the other hand, the necessity of formal variables has been contested in semantic theory; in particular, Jacobson (1999) argues for a Variable Free Semantics, grounded on the observation that variables are not logically necessary for expressive purposes. For example, Quine 1960 'explains away' the variables of predicate logic, showing that any expression in the system can be translated into a semantically equivalent expression using only a set of six operators and the predicates themselves. More generally, any Turing complete language can be translated into Combinatory Logic, which makes no use of variables. To date, however, the issue of ASL loci has not been systematically examined from the perspective of Variable Free Semantics.

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 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.

In Section 7, 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. After developing an account of verbal agreement and underspecification in Section 7.2, I show that the constraints on co-reference fall out for free under a generalized form of Jacobson's (1999) z-combinator: the syntax ensures that a pronoun and its antecedent must share the same locus.

1.1 Languages, Methodology, and Transcription Convention

Throughout this paper, unless otherwise noted, I will be discussing a specific dialect of ASL, that of "Signer 1," who is a Deaf native signer (a deaf child of deaf, signing parents). At least one other semantic dialect seems to exist for a number of signers; below, I discuss the observed variation across signers when relevant.

All data were gathered following the 'playback method' (Schlenker 2011). The 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 judgments using a 7 point scale (7 is perfectly grammatical) and answers to any interpretation questions. Judgments could then be repeated on separate days or with different signers. Appendix C provides a full list of judgment tokens, indexed by signer[2].

In the body of the paper, I collapse the judgments of Signer 1 into a binary distinction for ease of exposition: average ratings of 4 or less receive a '*' to indicate ungrammaticality, average ratings greater than 4 receive no star[3]. The judgment list in the Appendix uses the uncollapsed 7 point scale.

[2]Several notes on these judgments are pertinent to mention here. For sentences which exemplify new observations or are critical for the present argument, at least three judgments were elicited. When judgments differed between signers, further sentences were tested to establish the consistency of Signer 1's judgments; robustness was established both by retesting prerecorded videos and by testing novel sentences that replicated the argument (e.g. sentences with the same structure but different lexical items). Many paradigms also replicate or build on previously reported findings in the literature; these are discussed in the paper. Finally, some early examples in this paper are replicated in more complex forms by examples later in the paper. These are summarized in Appendix C.

[3]A 4.0 was chosen as the cut-off point for grammaticality to best represent the judgment contrasts for the examples in this paper, and to calibrate them to the binary judgments that have been reported in the literature for similar sentences. Here, mean judgments range from 2.75 to 7.0, and roughly cluster into two categories, with no judgments between 4.0 and 6.0.

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.

In ASL, loci may be established in several ways. Manually, a locus may be established by signing the NP with a hand located at the locus, or by pointing to the locus immediately before the NP is signed. Additionally, loci can be established via non-manual markers, either by leaning the body towards the locus or by directing eye-gaze towards the locus. Frequently, both manual and non-manual strategies appear together, but non-manual markers may establish a locus even in the absence of manual locus-marking. In this paper, we focus entirely on examples with (at least) manual locus-marking, in order to eliminate uncertainty that loci are being used. This means that non-manual markers are mostly irrelevant for present purposes, except in the few cases when I claim that *no* locus has been established (as in Section 5.2).

Three pronominals are discussed. IX-i (short for 'index') is a pronoun ('he, she'), signed by pointing at locus i. I take POSS-i to be the possessive pronoun ('his, her'), signed by directing a B-handshape (flat hand with fingers together) at locus i. Finally, I take SELF-i to be the reflexive pronoun ('himself, herself'), signed by directing an A-handshape (fist with thumb sticking out) at locus i. Both POSS-i and SELF-i have received attention in the sign language literature (for POSS-i, see Abner 2012; for SELF-i, see Fischer & Johnson 2012 and Koulidobrova 2009); for our purposes here, what matters is the basic observation that all three signs receive their meaning through association with a previous constituent that activated the same locus.

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. 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) 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.'

Figure 1 provides word-by-word images of sentence (2); the signer disambiguates the two possible readings by pointing ipsilaterally (as in Fig. 1, a) or contralaterally (as in Fig. 1, b).

2.1 Evidence against a purely referential analysis

Pointing gestures may be used even in spoken language, with a non-compositional, referential interpretation. For example, Giorgolo 2010 gives a formal analysis of gestures: for him, when a gesture co-occurs with a linguistic constituent, the denotation of the gesture intersects with the denotation of the constituent, thus restricting its meaning. The effect of a pointing gesture is to restrict the denotation of a free variable to a specific discourse referent. As a null hypothesis, we might then hypothesize that ASL loci serve a similar function. Thus, the "Referential Hypothesis," is that all uses of loci can be analyzed in a manner which can be paraphrased in terms of free variables. (We note that versions of this hypothesis have been assumed for ASL by a number of authors, such as Graf and Abner 2012.)

Figure 1: Word-by-word images of sentence (2)

A strong instantiation of this hypothesis is sub-hypothesis that the meaning of the pronoun itself (IX-i) is always referential, and that, like pointing gestures in spoken language, it picks out some some free individual-type variable in the context. A specific formalization of this hypothesis is given in (3).

(3) **Referential pronoun hypothesis:** in a context c, the value of a locus is provided by the assignment function g_c, where $g_c(i)$ is the e-type individual that corresponds to the NP indexed at locus i in c.

a. $\forall$ assignment functions s, $[\![\text{IX-}i]\!]^s = [\![\text{IX-}i]\!]^{g_c} = g_c(i)$.

Under this hypothesis, if the context parameter is never shifted (as on Kaplanian assumptions), then g_c is also fixed, so no pronoun can receive a bound reading. As it turns out, Quer 2005 (among others) has argued that ASL *does* have a context-shift operator (called 'role-shift'), phonologically indicated by shifting the position of the body. However, in the following examples, and throughout the examples in this paper, role-shift is never phonologically realized (and thus, never indicated in the gloss). Moreover, the only pronoun claimed to be affected by role-shift in ASL is the first person pronoun; in our examples here, all relevant pronouns are third-person.

Further, even in the presence of a (covert) context-shifting operator, the referential pronoun hypothesis makes specific predictions. Specifically, in cases of overt role shift, ASL has been shown to be a "Shift Together" language (Schlenker 2014c), meaning that two pronouns with no intervening context shifters must vary with respect to the same context-shift operator (Anand and Nevins 2004).

With or without covert context shifters, the referential pronoun hypothesis generates incorrect predictions. In particular, pronouns can undergo true quantificational binding: in (4) and (5), the meaning of the pronouns co-varies with the quantifiers. Of note, in both examples, the two pronouns vary with respect to different operators; this cannot be achieved even with a shifting context parameter.

(4) [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) [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}.'

It should be noted that the judgments of (4) and (5) show variation between signers. Although the grammaticality and interpretation of the two sentences are stable for Signer 1, a number of signers give degraded judgments, particularly for sentence (5) (see Appendix C for specific judgments).

On the other hand, even signers who reject (5) report the availability of bound readings of pronouns under *only*. ASL, like English, has focus sensitive operators (Wilbur 1994); as in English, pronouns under these operators are ambiguous, as seen in the two readings of (6). Section 4.2 will return to examples of this sort in more depth; for now, however, it is sufficient to note the existence of reading (6b), in which the pronoun co-varies in the focus alternatives[4]. With no context-shifting environment in sight, this can only be achieved through quantificational binding.

(6) IX-a JOHN$_a$ ONLY-ONE SEE POSS-a MOTHER.

a. ✓ [only John$_x$] $\lambda y.y$ saw x's mother (=No other boy saw John's mother.)

b. ✓ [only John$_x$] $\lambda y.y$ saw y's mother (=No other boy saw his own mother.)

Thus, even signers who are hesitant to accept (5) allow some cases of quantificational binding, thereby falsifying the hypothesis in (3).

A weaker instantiation of the referential hypothesis is that pronouns carry two variables: a covert individual-variable k that can be bound, and the phonologically overt free variable i, that ranges over sets of individuals, and restricts the values that can be taken by the covert variable. This is formalized in (7). Intuitively: loci index *sets*; pointing to a locus selects an individual from that set.

(7) **Referential locus hypothesis:** in a context c, the value of a locus is provided by the assignment function g_c, where $g_c(i)$ is the set of type $\langle e, t\rangle$ that corresponds to the noun indexed at locus i in c.

a. $\forall$ assignment functions s, $[\![\text{IX-}i_k]\!]^s = s(k)$ if $s(k) \in g_c(i)$
$\#$ otherwise

We note that (4) and (5) satisfy this hypothesis if we let $g_c(a)$ be the set of boys and $g_c(b)$ be the set of girls. Co-variation occurs because the covert individual variables are bound.

To test this hypothesis, we need to consider cases where the set of individuals indexed at a is a subset of the set of individuals indexed at b. In such a case, pointing to locus b should not be able to disambiguate antecedents, since the possible denotations of the pronoun at b will necessarily include all individuals indexed at a (that is, $g_c(a) \subseteq g_c(b)$).

Example (8) falsifies this hypothesis. In this sentence, the NPs "ALL BOY" and "ALL OTHER BOY" are indexed at two distinct loci. Through a pair of multiple-choice inference questions, consultants were

[4] I say "focus alternatives" not to necessarily commit to a specific theory of *only*, but simply to describe the empirical covariation of the meaning.

asked to identify how many groups of boys were under discussion (one or two) and to identify what the pronoun could refer to ("John and Bill are two relevant boys. What did John tell Bill? (i) That John would win. (ii) That Bill would win."). All consultants allowed readings in which the two NPs refer to different sets of boys, but importantly, Signer 1 additionally allowed a reading in which a single group of boys is under discussion, so both quantified NPs range over the same set. Critically, in all cases, pointing to a locus disambiguates the logical antecedent: IX-a yields the judgements in (8a,b); IX-b reverses them.

The present hypothesis makes the wrong predictions. Specifically, on the reading in which both quantified NPs range over the same set, the denotations of the two loci must be the same: $g_c(a) = g_c(b)$. Thus, if the use of a locus merely imposes a presupposition on the denotation of a pronoun, then (7) wrongly predicts that pointing to locus a or b will *not* disambiguate the binder, since both impose the same presupposition. Specifically, (7) incorrectly predicts that (8) should have the reading in (8b), since $s(y) \in g_c(a)$.

(8) [ALL BOY]$_a$ TELL [ALL OTHER BOY]$_b$ IX-a WILL WIN.

a. ✓ '[All the boys$_a$] $\lambda x.x$ told [all the other boys$_b$] $\lambda y.y$ that x would win.'

b. ✗ '[All the boys$_a$] $\lambda x.x$ told [all the other boys$_b$] $\lambda y.y$ that y would win.'

As noted above, the "one-group" reading, which was necessary to construct the relevant test case, is not available for all signers, but an analogous argument can be constructed with the bound reading of *only* sentences like the one in (9)[5]. As before, multiple-choice inference questions probed the meaning of (9), showing: (i) as with its English correlate, the ASL sentence entails that, according to Jessica, there's some property that holds of Billy that doesn't hold of anyone else in some set of salient alternatives, (ii) Jessica herself may be a member of this alternative set, (iii) the pronoun POSS-b can be bound, varying in the focus alternatives ("According to Jessica, no other students did their own homework"), can be free and co-referential with Billy ("...no other students did Billy's homework"), but *cannot* be co-referential with Jessica, indexed at locus a (Unavailable: "...only Billy did Jessica's homework").

(9) IX-a JESSICA$_a$ TELL-ME IX-b [BILLY ONLY-ONE]$_b$ FINISH POSS-b HOMEWORK.

a. ✓ Jessica$_x$ told me [only Billy$_y$] $\lambda z.z$ did z's homework.

b. ✓ Jessica$_x$ told me [only Billy$_y$] $\lambda z.z$ did y's homework.

c. ✗ Jessica$_x$ told me [only Billy$_y$] $\lambda z.z$ did x's homework.

However, the present hypothesis incorrectly predicts the pathological third reading in (9c) to be available. Specifically, in order to get the bound reading in (9a), the covert variable associated with POSS-b must be

[5] A necessary condition for these arguments to go through is the ability to know the extension of the two NP sets from the truth conditions. Note, for example, that simple examples with indefinites (as in (i)) are not sufficient to make the point here, because the loci of two indefinites, although they index the same restrictor NP, could denote different non-overlapping subsets of that NP.

(i) SOMEONE$_a$ TELL SOMEONE$_b$ IX-a WILL WIN.
'Someone told someone that the former would win.'

However, when the quantifier has universal force, the truth conditions of the sentence reveal that the two NP sets are in fact identical. Sentences with *only* work as well, because *only* takes universal force over the focus alternatives (negating all of them). A third set of examples that could serve to prove the case are indefinites that scope under another operator, as in (ii); in these cases, the domain of the indefinites are reflected in the truth conditions. Some such examples are discussed by Schlenker (2011).

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

defined for all focus alternatives, including Jessica. Under the hypothesis in (7), this means that Jessica must be an element of $g_c(b)$. Thus, $g_c(a) \subseteq g_c(b)$, and regardless of which NP binds POSS-b, the presupposition that $[\![\text{POSS-}b]\!]^s \in g_c(b)$ is satisfied. The referential hypothesis therefore wrongly predicts the existence of the reading in (9c), which entails that Jessica told the speaker that Billy did Jessica's homework. The judgments in (9) seem to be robust even for signers who reject the relevant reading of (8), thus falsifying the hypothesis in (7) for these signers.

It is perhaps telling that the most robust examples for falsifying the referential hypothesis are those which involve the focus alternatives of *only*. As I will discuss in §4.2, these environments differ from the other examples here in that they allow morphosyntactic features to remain *uninterpreted* (for example, gender or person features on pronouns). Section 3 will provide evidence that viewing loci as features is a productive line of analysis. The referential constraints that appear for some signers on the data discussed here could then be seen as the semantic interpretation of this morphosyntactic feature. The exact nature of this semantic interpretation is beyond the scope of this paper.

In short, the referential hypothesis has been falsified for several different semantic dialects of ASL. Thus, unlike gestures used in spoken language, loci in ASL do more than pick out discourse referents; additionally, they can reflect the logical structure of the sentence. In this capacity, 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, loci are the overt phonological manifestation of variable names.

3 Variables or Features?

When we eliminate purely referential analyses, there are two primary 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:

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

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

Note that the formulation of the feature-based hypothesis does not say that the features in question are *person* features (contra Neidle et al 2000). This frees us from any extra assumptions about the way that they will function, and also allows the possibility that person features may exist elsewhere in ASL. (This latter position has been argued by Lillo-Martin and Meier (2011), who show that first person pronouns often exhibit exceptional agreement patterns which may be explained by a first-person 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 that 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.

On the other hand, the feature-based analysis seems to potentially overgenerate; there are many situations in which locus-sharing yields ungrammaticality. I give a pragmatic explanation for these sentences, arguing that they are unnecessarily ambiguous.

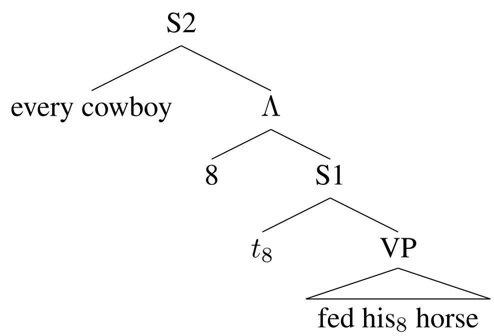
3.1 Binding with variables.

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: the interpretation of any given variable varies over a number of possible values (which may be manipulated by higher operators), but when two variables of the same name appear free in some sub-expression, then the two 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.

The standard account of variables in natural language semantics takes its cue from Tarski (1933/1952), who introduces the concept of **assignment functions**, which map locally unbound variables (taken to be the natural numbers 1, 2, 3, ...) to values (such as individuals: 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. A familiar presentation of assignment functions is given by Heim & Kratzer (1998, p. 111), whose notational conventions I follow below.

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 $[\![\text{8 S1}]\!]^g$ 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. An example is given in (12) and (13).

(12)



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

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 term can be expressed as a term with no free variables. In VFS, pronouns denote the identity function over individuals; the denotation of a pronoun is given (14). The argument slot introduced by the pronoun can then be passed through the syntax through function composition, formalized with the 'geach' operator (in (15)). Finally, binding is accomplished using Jacobson's z-combinator, which merges two argument slots (shown in (16)).

(14) $[\![\text{he}]\!] = \lambda x.x$

(15) *Semantic definition of function composition via Geach (**g**):*

a. $\boldsymbol{g}(f) = \lambda h \lambda y[f(h(y))]$

(16) *Semantic definition of binding (**z**):*

a. $\boldsymbol{z}(V_{\langle\alpha,\langle e,\beta\rangle\rangle}) = \lambda f_{\langle e,\alpha\rangle} \lambda x_e[V(f(x))(x)]$

Examples (17) and (18) demonstrate how **g** and **z** interact in the grammar to achieve binding. In (17), 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 (18), the argument slot is passed up as before; however, the **z** combinator acts on the verb, merging the e-type argument of *think* with the e-type argument of *laugh*. The extension of the sentence is a truth value.

(17) He laughed.

a. $[\![\text{laughed}]\!] = \lambda x_e.\text{laughed}'(x)$

b. $[\![\mathbf{g}(\text{laughed})]\!] = \lambda f_{\langle e,e\rangle} \lambda y_e.\text{laughed}'(f(y))$

c. $[\![\mathbf{g}(\text{laughed})(\text{he})]\!] = \lambda y_e.\text{laughed}'(y)$

(18) John thinks he laughed.

a. $[\![\text{thinks}]\!] = \lambda p_t \lambda x_e.\text{thinks}'(p)(x)$

b. $[\![\mathbf{z}(\text{thinks})]\!] = \lambda f_{\langle e,t\rangle} \lambda x_e.\text{thinks}'(f(x))(x)$

c. $[\![\mathbf{z}(\text{thinks})(\mathbf{g}(\text{laughed})(\text{he}))]\!] = \lambda x_e.\text{thinks}'(\text{laughed}'(x))(x)$

d. $[\![\mathbf{z}(\text{thinks})(\mathbf{g}(\text{laughed})(\text{he}))(\text{John})]\!] = \text{thinks}'(\text{laughed}'(\text{john}'))(\text{john}')$

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.

On the variable-free side, both empirical and theoretical arguments have been given; many of these are discussed in Jacobson 1999. One striking empirical advantage discussed by Jacobson 2000 is the existence of 'paycheck' pronouns, which arise as an automatic prediction of the variable-free system.

On theoretical grounds, Jacobson 1999 argues that VFS is simply more parsimonious: VFS needs not posit indices and assignment functions in the semantic ontology, which are otherwise unmotiviated. Of particular relevance, Jacobson 1999 observes that indices have no phonological manifestation in spoken language — we do not pronounce "he$_x$" and "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.

4 Evidence against variables: no accidental variable capture

As we saw in Section 3.1, the variable-full theory 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; thus, two occurrences of the same locus in the same binding domain must receive the same interpretation. This yields a strikingly non-compositional power: two pronouns, which may be syntactically independent, may nevertheless be forced to receive the same value from higher operators by virtue of their phonological forms.

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 (19) prevent the pronouns from referring to the same individual. However, although both pronouns in (20) bear identical features, they nevertheless can refer to different individuals.

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

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

On the hypothesis that loci are features, a single locus can be shared by two different individuals, just as the [+masculine] feature is shared by the two pronouns in (20).

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.

4.1 Locus reuse in sign language

Can one locus be used for two different individuals? The preliminary answer is clearly yes: although theoretically infinitely many loci exist, psychological constraints prevent signers from using more than a small number (about four) in a given discourse. Thus, when a large number of individuals are discussed, loci must be recycled in order to keep track of the relevant relations between them.

The discourse in (21) offers one such example, where the three subjects are all indexed at locus a, and the three objects are indexed at locus b.

(21) KINDERGARTEN CLASS STUDENTS IX-arc-ab, STUDENTS PRACTICE DIFFERENT COMPLIMENTS.
CL-3+IX-1 IX-a ALAN TELL IX-b BILL IX-a ADMIRES IX-b.
CL-3+IX-2 CHARLES-a TELL IX-b DANIELLE IX-a LIKES POSS-b STYLE.
CL-3+IX-3 EVE-a TELL IX-b FRANCIS IX-a THINK IX-b HANDSOME.
'In a Kindergarten class, the students were practicing different compliments.
First, Alan$_i$ told Bill$_j$ that he$_i$ admires him$_j$.
Second, Charles told Danielle that he likes her style.
Third, Eve told Francis that she thinks he's handsome.'

The basic observation that loci can be recycled is not new, although the literature has generally focused on the semantic structures in which locus reuse is pragmatically felicitous. For example, in several sign languages, a possessive relation can be communicated by indexing an object at the locus of its possessor (Japanese Sign Language: Morgan 2008, Kata Kolek: Perniss and Zeshan 2008). An example from Japanese Sign Language is given in (22): when HOUSE is signed near the signer, it is understood as the signer's house; when it is signed at the locus of a third person, it is understood as that person's house. What is relevant in these examples is that the same locus is reused to index two different individuals: the possessor (here, a person) and the possessee (here, a house).

(22) **Japanese Sign Language:**
HOUSE-1st HOUSE-a LITTLE-LITTLE.
'His house is not far from my house.' (From Morgan 2008)

A second case of locus-sharing underlies cases of "locative shift" (Padden 1988): when a locus is established for a geographic location (e.g. PARIS-a), pointing to the locus (e.g. IX-a) can retrieve either the geographic location or an individual associated with that location. Example (23) replicates an example from Schlenker 2012.

(23) IX-b JOHN-b WORK [IX-a PARIS]-a. SAME WORK [IX-c NEW YORK]-c.
IX-a, IX-1 HELP IX-a. IX-c, IX-1 NOT HELP IX-c.
'John works in Paris and also works in New York.
There (Paris), I help him. There (New York), I don't help him.'

Coordination structures provide a third example. Schlenker 2011 (Appx. 2) discusses cases from ASL where two disjuncts are indexed in the same location. A replicated version of his examples is given in (24). Davidson 2013 provides further discussion of coordination in ASL.

(24) PRESIDENT ELECTION, [WHITE MAN]-a IX-a WON'T WIN.
THIS YEAR, [BLACK MAN]-c OR [ASIAN MAN]-c WILL WIN.
IX-c WILL WIN AHEAD.
'A white man won't win the presidential election.
This year, an African American or Asian American will win.
He [=the winner] will win by a large margin.'

The cross-linguistic generalization seems to be: locus reuse is possible, but seems to be governed by pragmatic factors, such as having a salient contextual relationship between co-located individuals (such as possession).

However, the recycling of loci is not, in itself, enough to argue against a variable-based analysis of loci. After all, two occurrences of a logical variable may be semantically independent if there is an intervening operator. To make this more concrete, consider the predicate logic expression in (25a): the two occurrences of x are independent, so the meaning of the expression denotes the same proposition as the α-equivalent expression in (25b).

(25) a. $\exists x[P(x)] \wedge \exists x[Q(x)]$
b. $\exists x[P(x)] \wedge \exists y[Q(y)]$

Thus, the critical configurations to test are exactly the cases of variable capture introduced in §3.1: we need two co-located pronouns to appear free in the same sub-expression, as in (26).

(26) ...NP$_a$[...NP$_a$[...IX-a...IX-a...]]...

The following two sections shows that such configurations are attested, but do *not* force co-reference. To my knowledge, this is the first time that such sentences have been reported in the literature.

4.1.1 Locus sharing in the same clause

Sentence (27) provides the first counter-example to the variable-based analysis. Here, both JOHN and MARY are signed at locus a, and the two instances of IX-a are free within the embedded sentence, thus exemplifying the configuration in (26). The same holds for BILL and SUZY, both signed at locus b.

Nevertheless, the sentence is grammatical, and the two instances of IX-a can retrieve different individuals. As discussed above, this cannot be captured under the variable-based analysis.

(27) EVERY-DAY, JOHN_{a} TELL MARY_{a} IX-a LOVE IX-a. BILL_{b} NEVER TELL SUZY_{b} IX-b LOVE IX-b.
'Every day, John_i tells Mary_j that he_i loves her_j. Bill_k never tells Suzy_l that he_k loves her_l.'

In contrast, the grammaticality of (27) comes automatically under the agreement analysis, in which an NP may bind any pronoun that agrees in locus.

A possible argument against this example is to maintain 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, there is evidence against this analysis from both production and reception. In production, the signer, who has good meta-linguistic awareness, was asked explicitly to place the pairs of people at the same locus; the sentence above is what was produced and evaluated. Then, after watching the video played back to himself, the signer reported that the sentence was "technically ambiguous," with a possible meaning that John tells Mary that she likes him, but that this second meaning "doesn't make sense" for pragmatic reasons. In particular, the subject reported that if the verb in the sentence were changed from TELL to ASK, the other binding pattern would be preferred.

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 (27), 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)[6], and the final reading is ruled out by world knowledge (specifically, it's weird to tell someone else about their own preferences).

This analysis is supported by the observation that sentence judgments decrease when ambiguity increases. For example, (28) is parallel to (27) except that Condition B no longer eliminates readings. In a paired paradigm, (27) receives a rating of 6/7; (28) receives a rating of 4/7.

(28) * EVERY-DAY, JOHN_a TELL MARY_a IX-a THINK IX-a SMART. BILL_b NEVER TELL SUZY_b IX-b THINK IX-b SMART.
'Every day, John tells Mary that he thinks {he/she} is smart. Bill never tells Suzy that he thinks {he/she} is smart.

Second, as we saw in §4.1, locus reuse is pragmatically facilitated by the existence of a salient contextual relationship (love) between the two co-located individuals. Here, opposing loci are used to indicate a contrast between the two pairs of individuals; both pairs have a parallel, salient relationship.

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.

[6] For a variable-free treatment of Condition B, see Jacobson 2007. Since this analysis makes no use of indices/variables, it can be transferred over to ASL with no additional work. See Section 7.3.3 for a brief discussion about Condition A in ASL.

4.2 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 a lambda operator or free and co-referential with the referential NP.

(29) 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.)*

American Sign Language, too, contains lexical items which are focus sensitive (Wilbur 1994, Wilbur and Patschke 1998), including at least three different signs that correspond roughly to English *only*: these are sometimes glossed ONLY, ONLY-ONE, and THAT'S-ALL (Wilbur and Patschke 1998).

Both ONLY (homophonous in ASL with ALONE, ALWAYS, and SOMEONE), and THAT'S-ALL (homophonous with FINISH and the perfect aspect marker) are able to associate with any focused material in the phrase. ONLY-ONE always appears adjacent to an NP (either the left or the right). Like prenominal *only* in English, it necessarily associates with the NP. In the following discussion, I focus on the form ONLY-ONE in order to eliminate irrelevant ambiguity from homophony and focus-association.

In ASL, focus-marking is indicated primarily with non-manual markers such as body leans (Wilbur 1999, Wilbur and Patschke 1998). However, since focus-association is syntactically determined with ONLY-ONE, non-manual markers will be omitted from glosses below for ease of notation.

Example (30) provides sentences with ONLY-ONE occurring on either side of an NP. Both sentences entail that the predicate (getting an A) does not hold of any alternatives to Kim.

(30) a. ALL KNOW KIM ONLY-ONE GET-A
'Everybody knows that only Kim got an A.'
b. KNOW WHAT? ONLY-ONE KIM GET-A
'Know what? Only Kim got an A.'
(Nobody besides Kim got an A.) (Examples from Wilbur 1994)

As in English, when a pronoun appears under ONLY-ONE, its interpretation is ambiguous between a referential reading and a reading in which it varies in the focus alternatives. Example (31) is repeated from (6).

(31) IX-a JOHN-a ONLY-ONE SEE HIS-a MOTHER.
a. [Only John$_x$] $\lambda y.y$ saw his$_x$ mother. *(Isabelle didn't see John's mother.)*
b. [Only John$_x$] $\lambda y.y$ saw his$_y$ mother. *(Isabelle didn't see her own mother.)*

4.2.1 Multiple pronouns under *only*/ONLY-ONE

Returning to English, we observe that when two pronouns appear under *only*, there are four possible readings, including two mixed readings, with one pronoun bound and one free[7]. The four readings for the sentence in (32) are shown in (33) with disambiguating contexts. The mixed readings are given in (b) and (c).

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

[7]The story is in fact more complex, but in ways orthogonal to our discussion here. For discussion of Dahl's Puzzle (Dahl 1974), see in particular Fox 2000 and Kehler and Buring 2007. For relevance to indexical pronouns, see Kratzer 2009.

(33) a. ***Bound-bound*****:** [Only Billy$_x$] $\lambda y.y$ told y's mother y's favorite color.
Every day, Billy's class is supposed to share a new fact about themselves with their family; this week, they were each supposed to tell their mothers their favorite color. However, only Billy did the assignment this week.

b. ***Free-bound*****:** [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.

c. ***Bound-free*****:** [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.

d. ***Free-free*****:** [Only Billy$_x$] $\lambda y.y$ told x's mother x's favorite color.
Billy is embarrassed that his favorite color is pink, and, in particular, doesn't want his mother to find out. In the end, though, it was Billy himself who spilled the beans.

This syntactic construction provides a second instance of the schema in (26). Thus, if ASL loci are variables, then the use of loci should make mixed readings unavailable. In particular, when two spatially co-indexed pronouns appear under *only*, 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. In the ASL sentence in (34), both possessive pronouns (POSS) are indexed at locus b, the locus of BILLY. All four readings are attested for (34) that are attested for the parallel English sentence in (32).

(34) 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.*

These judgments were tested multiple times in a variety of different ways. First, sentence (34) was signed by Signer 1 and recorded. The subject (who is fluent in English) was then presented with English descriptions of four contexts that disambiguate the four readings, as in (33) above. The subject was asked to judge (yes or no) whether the target sentence could be used felicitously to describe each context. It's important to clarify that this task is not one of judging logical *consistency* (since, for example, the bound-bound reading might happen to be true in a world where (33a) or (33b) holds), but rather, whether the meaning of the sentence *follows* from the context. For each context above, there is only one reading of the sentence that follows without additional information[8].

[8]To establish the robustness of this task, it's important to confirm that it does indeed produce negative results in some cases. Sentence (iii) provides one such example: here, the ASL sentence, like the English gloss, lacks a reading where the possessive pronoun is free and co-referential with the speaker. In ASL, the consultant reported that (iii) cannot be used to describe the context in (iv), even though the two are logically consistent. My intuition for the English gloss is exactly parallel.

(iii) ONLY-ONE STUDENT-a SEE HIS-a MOTHER WHO? ME.
'The only student who saw his mother was me.'

(iv) ***Infelicitous context (possessive pronoun co-referent with speaker)*****:**
The speaker's mother was in a crowd, and all his friends were looking for her. The speaker saw her; nobody else did.

This context-matching task was paired with an inference task in which the subject was asked to judge whether a given inference about the other children follows from some reading of the sentence. For example, to judge the availability of the reading targeted by (33b), the subject was asked whether it follows from the sentence that "John did not tell Billy's mother John's favorite color." On both these diagnostics (context felicity and inference judgments), all four readings were judged to be available.

To identify fine-grained preferences, the subject was then asked to repeat the task giving judgments for each reading on a 7 point scale. All were rated highly: the bound-bound and free-bound readings were rated 7/7; the bound-free and free-free readings were rated 6/7.

Throughout the entire first set of judgments, written English was used for the contexts and inferential tasks to make certain that the judgments were being given for the target sentence and not for the contexts. However, to ensure that English was not influencing the judgments, the entire procedure was repeated later using only ASL. First, the four contexts were translated into ASL by Signer 1 (and checked by the author). At a later date, the entire procedure was repeated (using binary judgments), using the pre-recorded contexts in ASL. This was done both for the original subject and an additional subject.

In all cases, judgments were confirmed: all four readings were judged to be available. To capture these facts, the variable-based analysis would need to sacrifice the strong hypothesis in which loci directly correspond with variables.[9]

4.2.2 Uninterpreted features

On the feature based analysis, the example in (34) displays a striking similarity to the phenomenon of **uninterpreted features** in spoken language. The basic observation (generally attributed to lecture notes by Heim) is that phi-features (i.e. gender, person, and number) appear not to be interpreted on bound pronouns under focus-sensitive operators like *only*.

For example, both sentences in (35) have a bound and free reading; the bound reading entails that other members of a comparison set did not do their homework. Critically, though, this comparison set may contain individuals who do not bear the features of the bound pronoun. Thus, on the bound reading, (35a) entails that John didn't do his homework, even though he is not a female; (35b) entails that John didn't do his homework, even if he is not the speaker.

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

Turning to ASL loci, we observe exactly the same pattern: when a pronoun appears bound under *only*, the comparison set may contain individuals who do not share the locus of the pronoun. Thus, in (36), repeated from (9), the bound reading entails that, according to Jessica, she herself didn't do her own homework even though Jessica (at locus a) bears a different locus from Billy (at locus b).

(36) IX-a JESSICA$_a$ TELL-ME IX-b [BILLY ONLY-ONE]$_b$ FINISH POSS-b HOMEWORK.
 a. *Bound reading:* Jessica told me [only Billy$_y$] $\lambda z.z$ did z's homework.

Sentence (34) is exactly parallel: the two pronouns bear a locus, b, which is uninterpreted when the pronouns are bound by ONLY-ONE; thus, when bound, their value may range over individuals indexed at other loci (including Jessica, at locus a).

[9] 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, as shown in Kehler and Buring 2007.

Two general approaches have been taken for the puzzle of uninterpreted features. Kratzer (1998, 2009) and Heim (2008) propose that features on bound pronouns do not exist at LF, but instead are inherited via syntactic agreement. Jacobson (2012) argues that phi-features on bound pronouns *do* exist in the LF, but make no contribution to the focus-value of an expression.

Regardless of whether we adopt the syntactic analysis of Heim/Kratzer or the semantic analysis of Jacobson, though, the facts carry over directly to sign language. If loci are spatial features, then whatever mechanisms allow features to remain uninterpreted in focus alternatives in spoken language will allow loci to remain uninterpreted in focus alternatives in ASL.

Thus, the readings in (34) 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 (35) are uninterpreted.

5 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 4.2 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 an analysis of loci (whatever its final form) should be the same as an analysis of features elsewhere in language.

5.1 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 (37a,b)) or both of the arguments (as in (37c,d)).

(37) a. TELL_a: motion starts at the chin, and moves to the locus of the indirect object (here, locus a).
b. SEE_a: motion starts at the eyes, and moves to the locus of the direct object (here, a).
c. ${}_a\text{HELP}_b$: motion starts at the locus of the subject (here, a), and moves to the locus of the direct object (here, b).
d. ${}_a\text{GIVE}_b$: motion starts at the locus of the subject (here, a), and moves to the locus of the indirect object (here, b).

Example (38) 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.

(38) a. BOOK, JOHN_a ${}_a\text{GIVE}_b$ MARY_b. *(Match)*
b. * BOOK, JOHN_c ${}_a\text{GIVE}_b$ MARY_b. *(Mismatch subject)*
c. * BOOK, JOHN_a ${}_a\text{GIVE}_b$ MARY_c. *(Mismatch object)*
'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.

5.2 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 (39)). However, past tense verbs are underspecified in this respect: they can take either singular or plural subjects (as in (40)).

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

a. A boy sleeps.

b. * A boy sleep.

c. * Boys sleeps.

d. Boys sleep.

(40) *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 (41).

(41) HAPPY takes a subject at any locus.

a. JOHN_a HAPPY.

b. JOHN_b HAPPY.

The flip-side of underspecification is that there are also cases in which the verb is specified for a given feature, but the noun is not. Some examples of this for English number features are given in (42). (We note that the interpretation changes in each of the two cases; this is expected, given that the plural feature has a semantic effect. Critically, though, the interpretation is disambiguated by the predicate, not the noun.)

(42) a. Who {has/have} left? *(some dialects)*
b. The sheep {is/are} grazing in the field.

Again, a similar pattern holds for loci. In ASL, NPs may always be signed in a default position, articulated in a neutral location in front of the body, without establishing a locus. If we view these neutral forms as underspecified for spatial feature, we find that the pattern is exactly the same for ASL loci as for features in spoken language: a given structure is only ungrammatical if there is a *mismatch* of features.

(43) Mismatch conditions ungrammatical, but neutral arguments fine in either argument position
a. BOOK, JOHN$_a$ $_a$GIVE$_b$ MARY$_b$. *(Match)*
b. * BOOK, JOHN$_c$ $_a$GIVE$_b$ MARY$_b$. *(Mismatch subject)*
c. BOOK, JOHN $_a$GIVE$_b$ MARY$_b$. *(Underspecified subject)*
d. * BOOK, JOHN$_a$ $_a$GIVE$_b$ MARY$_c$. *(Mismatch object)*
e. BOOK, JOHN$_a$ $_a$GIVE$_b$ MARY. *(Underspecified object)*

We note that the non-manual markers on the neutral NPs in (43) also show no indication of agreement with the verb. First, although there is a slight ipsilateral head-tilt on neutral subjects, it appears regardless of whether the verbal agreement begins on the ipsilateral or contralateral side. Second, although most cases of locus establishment are accompanied by a brief eye-gaze towards the locus, all neutral forms tested above contain eye-gaze directed only at the camera.

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.

6 Interim summary

At this point, the strong loci-as-variables hypothesis has been falsified. Specifically, in Section 4, I showed two cases where the theory wrongly predicts variable capture and undergenerates readings.

On the other hand, it is 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. And indeed, weaker variable-based hypotheses may be available which maintain a connection between loci and variables, but do not fall subject to the same incorrect predictions. I will not go into detail on these possibilities here, but readers are referred to Schlenker 2014a, which presents a proposal for "featural variables," designed to account for the data presented in the present paper.

Even in the potential move to a weakened variable-based theory (as in Schlenker 2014a), it's important to note one critical property of the strong loci-as-variables hypothesis that must be abandoned—namely, the non-compositional power of the system to link the meanings of two pronouns through accidental variable-capture. This observation suggests a theory-neutral partial reinterpretation of the Variable-Free Hypothesis: specifically, VFS can be seen as a claim that the logic underlying natural language cannot force semantic coreference of syntactically independent constituents.

6.1 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 (2014b), 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.

In spoken language, feature sets with an unbounded number of features are significantly more difficult to find, likely due to differences between the two modalities. Nevertheless, Aronoff et al. (2005) provide one possible candidate in languages with “literal alliterative agreement.” In Bainouk and Arapesh, there is a large class of noun classes for native words; verbs and adjectives have affixes which agree with the class of their nominal arguments. The unmarked agreement strategy is reduplication of the final segment of the noun. So far, this is a standard case of a large but finite feature set (even with reduplication, since the languages have finite phonological inventories).

Where these languages become interesting, however, is in their treatment of loanwords, which do not fall into an existing noun class, and, importantly, may have non-native phonotactics. Specifically, Arapesh phonology generally prohibits word-final /s/, meaning that no native nouns end in /s/, and, consequently, that /s/ never appears as an agreement marker for native words. However, word-final /s/ *does* appear in loan words from English and Tok Pisin (such as /bas/, ‘bus’). Critically, when these words appear in agreement situations, the verbal agreement marker is not drawn from the existing set of agreement markers, but instead take a new form, derived from the phonological form of the nominal argument.

(44) **Reduplication of word final /-s/ in Arapesh**

bas sa-fiʔi a-ndaʔ pasim-as
bus s-came I-did flag.down-s
‘When the bus came, I flagged it down.’ *From Dobrin 1998, via Aronoff et al. 2005*

Thus, although feature sets with an unbounded number of features are typologically rare in the spoken modality, they nevertheless seem to be attested in language, especially in sign languages.

7 A feature-based fragment

This section presents a fragment which implements a feature-based analysis using Combinatory Categorial Grammar. As mentioned in Section 6.1, 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 the sake of exposition, I present it piece by piece through the prose of this section; however, the full fragment is repeated in one place in Appendix A.

In Categorial Grammar, subcategorization frames are explicitly listed in lexical entries. Only S and NP (and a few other categories) are taken to be primitives. All other categories are built from these primitives: if A and B are categories, then $A/_L B$ is a category and $A/_R B$ is a category.

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 (45). From here on, constituent values are represented as 2-tuples that contain a syntactic category and semantic denotation.

(45) *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. $\langle \text{B}, x\rangle \quad \langle \text{A}/_{\text{L}}\text{B}, f\rangle \quad \rightarrow \quad \langle \text{A}, f(x)\rangle$

As an example, a verb phrase in categorial grammar is assigned category S/$_{\text{L}}$NP, meaning, roughly, "give me an NP on my left, and I'll give you an S."

Below, annotations to the right of each line of the derivation indicate the deduction rule responsible for that step; for example, lex indicates a lexical entry; $f.a.$ indicates function application using the composition schema. Example (46) provides an example of a derivation for an English sentence.

(46) Edith ate cookies.

$$\cfrac{\cfrac{\text{Edith}}{\text{NP}}\ lex \qquad \cfrac{\cfrac{\text{ate}}{(\text{S}/_{\text{L}}\text{NP})/_{\text{R}}\text{NP}}\ lex \qquad \cfrac{\text{cookies}}{\text{NP}}\ lex}{\text{S}/_{\text{L}}\text{NP}}\ f.a.}{\text{S}}\ f.a.$$

(Note that subscripts R and L are left out below.)

7.1 Agreement verbs in ASL

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

Definitions for verbs are given in (47). Agreeing verbs specify a spatial feature on one or more of their NP arguments. Thus, $_a$HELP$_b$ (which moves in space from locus a to locus b) is of category (S/NP$_a$)/NP$_b$: it is a function which requires two NPs: one at locus a and one at locus b.

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

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

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

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

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

Verbal agreement is demonstrated with the following examples. Example (48) shows a successful derivation, in which both arguments match the argument specifications in the lexical entry of the verb. Example (49) shows an unsuccessful derivation; the predicate "$_a$HELP$_b$ BILL$_b$" requires an argument of category NP$_a$, but the subject is of category NP$_c$.

(48) JOHN$_a$ $_a$HELP$_b$ BILL$_b$.

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

(49) * JOHN$_c$ $_a$HELP$_b$ BILL$_b$.

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

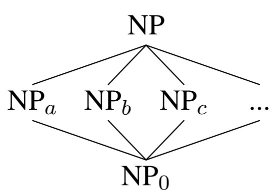
7.2 Underspecification as subsumption

As we saw in section 5.2, a spatial feature may be underspecified on either verbs or nouns: a non-directional verb may take NPs that are realized at any locus, and a neutral NP may be the argument of any form of a directional verb.

Underspecification has been discussed at length in the literature on constraint-based grammars (e.g. LFG of Kaplan and Bresnan 1982, HPSG of Pollard and Sag 1994; see also Bernardi and Szabolcsi 2007 for exposition and overview). The basic proposal within these theories is that syntactic categories are organized as partially ordered sets; then, being a satisfactory argument for a given function requires subsumption, not identity. In English, for example, NP_{plur} and NP_{sing} are both subsumed by the umbrella category NP. The past-tense verb *slept* (which doesn't select for the number of its subject) is of category S/NP; thus, both singular and plural NPs serve as satisfactory arguments.

Following this body of work, I posit the partial ordering in (50) for ASL loci. NP subsumes NP_i, and NP_i subsumes NP_0 (for all i). So, in a syntactic derivation, NP_0 derives NP_i, and NP_i derives NP (for all i).

(50)



Given this ordering, we can now give definitions for nondirectional verbs and for neutral NPs. A non-directional verb subcategorizes for the umbrella category NP. For example, the lexical entry for HAPPY is $\langle \text{S/NP}, \lambda x.\text{happy}'(x)\rangle$. Parallel to the English example above, all localized NPs serve as satisfactory arguments. Unlocalized (or neutral) NPs have the category NP_0. One can think of NP_0 as a "wildcard" NP; from it, you can derive any localized NP. Thus, the lexical entry for JOHN (not localized) is $\langle \text{NP}_0, j\rangle$.

In the present fragment, I realize this deduction pattern as a pair of combinators, $loc_1$and loc_2, with definitions given in (51). Although other strategies exist to capture underspecification (as in the formalisms mentioned above), this particular choice interfaces cleanly with the present formalism, as well as feeding a larger class of underspecification deductions discussed in 7.2.1.

(51) *Locus underspecification deductions for nouns and verbs (loc):*

a. $\text{loc}_1 = \langle\ \text{NP/NP}_i\ ,\ \lambda x.x\ \rangle$

b. $\text{loc}_2 = \langle\ \text{NP}_i\text{/NP}_0\ ,\ \lambda x.x\ \rangle$

Example derivations are given in the following. (52) shows verbal underspecification; (53) shows nominal underspecification.

(52) JOHN_a HAPPY.

$$\dfrac{\dfrac{\dfrac{\text{JOHN}_a}{\text{NP}_a}\,lex}{\text{NP}}\,loc_1 \qquad \dfrac{\text{HAPPY}}{\text{S/NP}}\,lex}{\text{S}}\,f.a.$$

(53) JOHN ${}_a$HELP$_b$ BILL$_b$.

$$\dfrac{\dfrac{\dfrac{\text{JOHN}}{\text{NP}_0}\,lex}{\text{NP}_a}\,loc_2 \quad \dfrac{\dfrac{{}_a\text{HELP}_b}{\text{(S/NP}_a\text{)/NP}_b}\,lex \quad \dfrac{\text{BILL}_b}{\text{NP}_b}\,lex}{\text{S/NP}_a}\,f.a.}{\text{S}}\,f.a.$$

7.2.1 Underspecification deductions via a family of combinators

Following standard Combinatory Categorial Grammar assumptions (Steedman 1985), the grammar also includes a small number of combinators. In particular, our system has the geach rule for function composition (repeated in (54)), and category-lifting (as in (55a)).

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

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

(55) *Definitions of category and type lifting:*

a. *Lift* = $\langle$ (A/(A/B))/B , $\lambda x f. f(x)$ $\rangle$

Simple motivations for these two combinators come from conjunction, assumed to combine two constituents of the same category. In (56), two subject-verb sequences are conjoined, to the exclusion of the direct object; however, using only function application, there is no way to combine the subject and verb into a constituent. The standard non-transformational solution to this puzzle is to allow function composition as a general combinatory rule (Ades and Steedman 1982): the geach combinator '**g**' is a Curried version of the two place function composition operator '∘.' In (57), *Alisa* and *all the children* have different categories/types but are nevertheless conjoined. The standard analysis of this is to allow type-lifting, raising an individual to a generalized quantifier (Partee and Rooth 1983); *Lift* is a generalized form of type-lifting.

(56) [Everyone tasted] but [nobody finished] the octopus pudding.
$\mathbf{g}(\text{everyone})(\text{tasted}) = \text{everyone} \circ \text{tasted} = \lambda x_e.\text{everyone}'(\text{tasted}'(x))$

(57) Alisa and all the children are in the backyard.
$\textit{Lift}(\text{Alisa}') = \lambda P_{\langle e,t\rangle}.P(\text{Alisa}')$

I further assume that these combinators can apply freely in the grammar, applying not only to lexical heads but also to other combinators. This departs from Quine 1960, Steedman 1985, and Jacobson 1999, who all assume that combinators exist in the grammar, but only apply to lexical heads and to the outputs derived by operators. (We note, however, that Jacobson 1999 posits an infinite family of geach operators, which can be derived by recursively applying the geach operator to itself.) In allowing combinators to apply to each other, I am following the line of Combinatory Logic (Curry and Feys 1958); this strategy has also been employed for linguistic analysis by Barker and Shan 2006.

As a result of this theoretical choice, although only two underspecification deductions are listed in the grammar (the two combinators in (51)), a larger class of underspecification deductions arise from interactions between the operators. Intuitively, the following generalization holds: an index may be *added* to an NP in the *domain* of a function; an index may be *removed* from an NP in the *range* of a function.

First, for example, consider what happens if we apply geach to the loc_1 operator. In the geach schema, we choose A to be NP and B to be NP$_i$. Applying (NP$^{\text{C}}$/NP$_i^{\text{C}}$)/(NP/NP$_i$) to NP/NP$_i$ (=loc_1), we get (NP$^{\text{C}}$/NP$_i^{\text{C}}$). This is shown in (58a).

Second, if a constituent is of category A/NP, we can function compose it with NP/NP$_i$ (=loc_1) to get a new constituent of category A/NP$_i$: in other words, if a verb phrase can take any NP, then it certainly can take a localized NP. Using **g** and *Lift*, this deduction is equivalent to the complex combinator given in (58b). If we apply **g** once more to this combinator, we add another argument on both the input and the output, yielding the combinator in (58c).

Full derivations for the deductions in (58) are given in Appendix B.

(58) a. $(\mathbf{g}'\ loc_1) = (\text{NP}^{\text{C}}/\text{NP}_i^{\text{C}})$

b. $((\mathbf{g}\ (Lift\ loc_1))\ \mathbf{g}) = (\text{A/NP}_i)/(\text{A/NP})$

c. $(\mathbf{g}\ ((\mathbf{g}\ (Lift\ loc_1))\ \mathbf{g})) = ((\text{A/NP}_i)/\text{C})/((\text{A/NP})/\text{C})$

To give a specific example, the schema in (58c) allows us to make the deduction in (59), adding an index to the subject argument of a transitive verb. This particular derivation should be flagged, since it will later feed the **z**-shift rule, allowing a localized pronoun to be bound.

(59)
$$\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\ lex}{\text{(S/NP}_i\text{)/NP}}\ (\mathbf{g}\ ((\mathbf{g}\ (Lift\ loc_1))\ \mathbf{g}))$$

The particular complex combinators listed in (58) will each be used at some point in the derivations of the next section, so to reduce ink, I will use loc_1' as a shorthand for $((\mathbf{g}\ (Lift\ loc_1))\ \mathbf{g})$.

7.3 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 combinators which explicitly make reference to features are the underspecification operators. All the instances of features appearing in the **g** or **z** rule 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 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 VP$^{\text{VP}}$; for ACD, it is of category 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 (60).

(60) *Lexical entries for pronouns (lex):*

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

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

When a pronoun is free, it is passed through the system using function composition, encoded with the Geach combinator. The syntax preserves the featural information of the gap, passing along subscripts.

(61) *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. $\mathbf{g}(f) = \lambda h \lambda y[f(h(y))]$

(62) *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 (63)). Thus, when the binder has category NP_i, the pronoun must also be of category NP_i (see (64)). In short: a pronoun and its binder must share the same locus.

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

a. $\mathbf{z}((\text{B/C})/\text{A}) = (\text{B/C})/\text{A}^{\text{C}}$

b. $z(V_{\langle\alpha,\langle\gamma,\beta\rangle\rangle}) = \lambda f_{\langle\gamma,\alpha\rangle}\lambda x_\gamma[V(f(x))(x)]$

(64) *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 (66) 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 (49)): the verb phrase subcategorizes for an NP with the wrong feature.

(65) JOHN_a LIKE SELF-a.

$$\dfrac{\dfrac{\text{JOHN}_a}{\text{NP}_a}\,lex \quad \dfrac{\dfrac{\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\,lex}{(\text{S/NP}_a)\text{/NP}}\,\mathbf{g}(loc'_1)}{(\text{S/NP}_a)\text{/NP}^{\text{NP}_a}}\,\mathbf{z} \quad \dfrac{\dfrac{\text{SELF-}a}{\text{NP}_a^{\text{NP}_a}}\,lex}{\text{NP}^{\text{NP}_a}}\,\mathbf{g}(loc_1)}{\text{S/NP}_a}\,f.a.}{\text{S}}\,f.a.$$

(66) * JOHN_b LIKE SELF-a.

$$\dfrac{\dfrac{\text{JOHN}_b}{\text{NP}_b}\,lex \quad \dfrac{\dfrac{\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\,lex}{(\text{S/NP}_a)\text{/NP}}\,\mathbf{g}(loc'_1)}{(\text{S/NP}_a)\text{/NP}^{\text{NP}_a}}\,\mathbf{z} \quad \dfrac{\dfrac{\text{SELF-}a}{\text{NP}_a^{\text{NP}_a}}\,lex}{\text{NP}^{\text{NP}_a}}\,\mathbf{g}(loc_1)}{\text{S/NP}_a}\,f.a.}{\textbf{can't combine}}\,f.a.$$

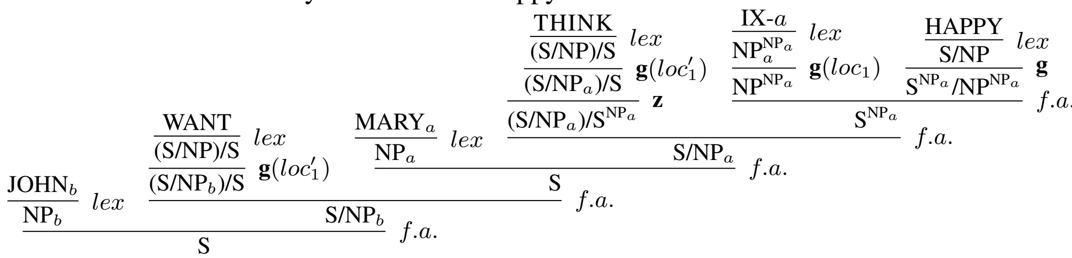
Critically, observe that we cannot just remove the subscripts from the two NPs: although we can use *loc* to drop the subscript from the subject, $\text{NP}_b \rightarrow \text{NP}$, we are *not* allowed to drop the subscript from the argument of the predicate. This follows from the generalization in §7.2.1 that subscripts may only be *added* to NPs in the input of a function.

7.3.1 Binding with multiple possible antecedents

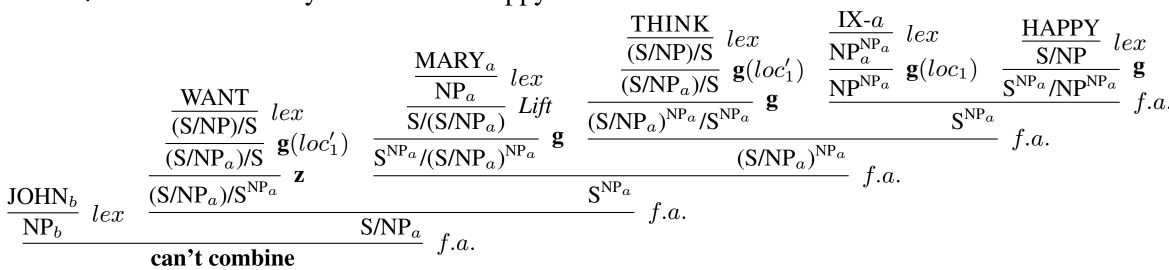
Examples (67) and (68) demonstrate that the fragment generates the generalizations discussed in Section 4. In particular, sentences are disambiguated when two potential binders are indexed at different loci. For example, the reading in (67a) has a corresponding syntactic derivation, but the reading in (67b) does not. On the other hand, when two NPs share the same locus (as in §4), then a pronoun can escape variable capture, and be bound by either.

(67) JOHN$_b$ WANT MARY$_a$ THINK IX-a HAPPY.

a. ✓ ‘John wants Mary to think she’s happy.’

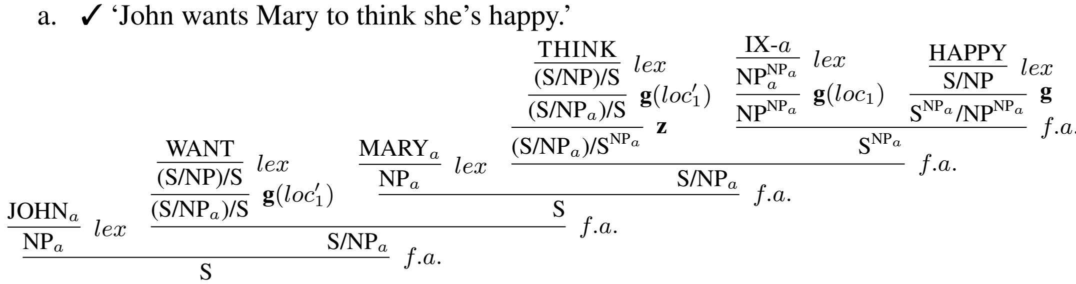


b. ✗ ‘John wants Mary to think he’s happy.’

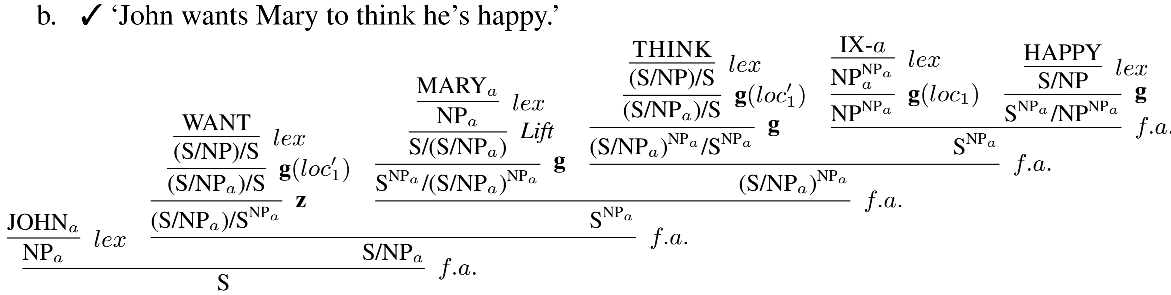


(68) JOHN$_a$ WANT MARY$_a$ THINK IX-a HAPPY.

a. ✓ ‘John wants Mary to think she’s happy.’



b. ✓ ‘John wants Mary to think he’s happy.’



7.3.2 Predictions about binding and underspecification

Several predictions fall out of this model. First, we predict that chains of bound NPs must all share the same locus. Note that in principle, the ability to bind and the ability to be bound are logically separate, as evidenced by the two different variables (x and y) in the gloss of sentence (69).

(69) John said he likes himself.
= John $\lambda x.x$ said x $\lambda y.y$ likes y.

However, in the current fragment, pronouns bear the category $\text{NP}_i^{\text{NP}_i}$, with matching subscripts on the base NP and the superscript NP. Since binding chains must be passed through a pronoun, and this pronoun cannot change the spatial feature, the whole chain must share the same locus. A grammatical sentence and derivation are shown in (70).

(70) JOHN$_a$ SAY IX-a LIKE SELF-a.

$$\dfrac{\dfrac{\text{JOHN}_a}{\text{NP}_a}\,\textit{lex} \quad \dfrac{\dfrac{\dfrac{\dfrac{\text{SAY}}{\text{(S/NP)/S}}\,\textit{lex}}{\text{(S/NP}_a\text{)/S}}\,\mathbf{g}(loc'_1)}{\text{(S/NP}_a\text{)/S}^{\text{NP}_a}}\,\mathbf{z} \quad \dfrac{\dfrac{\text{IX-}a}{\text{NP}_a^{\text{NP}_a}}\,\textit{lex} \quad \dfrac{\dfrac{\dfrac{\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\,\textit{lex}}{\text{(S/NP}_a\text{)/NP}}\,\mathbf{g}(loc'_1)}{\text{(S/NP}_a\text{)/NP}^{\text{NP}_a}}\,\mathbf{z} \quad \dfrac{\dfrac{\text{SELF-}a}{\text{NP}_a^{\text{NP}_a}}\,\textit{lex}}{\text{NP}^{\text{NP}_a}}\,\mathbf{g}(loc_1)}{\text{S/NP}_a}\,f.a.}{\text{S}^{\text{NP}_a}/\text{NP}_a^{\text{NP}_a}}\,\mathbf{g}}{\text{S}^{\text{NP}_a}}\,f.a.}{\text{S/NP}_a}\,f.a.}{\text{S}}\,f.a.$$

We note that, with respect to this prediction, the current analysis is on par with a variable-based analysis: Under the variable-based analysis, the prediction falls out from the standard assumption that NPs bear a single index which determines both whether a pronoun is bound and whether it binds any subsequent pronouns.

Second, because binding is accomplished through the same mechanism as verbal agreement, the model predicts that pronoun binders can be underspecified, parallel to cases with directional verbs. This prediction is also borne out. A grammatical sentence and derivation are shown in (71).

(71) JOHN LIKES SELF-a.

$$\dfrac{\dfrac{\dfrac{\text{JOHN}}{\text{NP}_0}\,\textit{lex}}{\text{NP}_a}\,loc_2 \quad \dfrac{\dfrac{\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\,\textit{lex}}{\text{(S/NP}_a\text{)/NP}}\,\mathbf{g}(loc'_1)}{\text{(S/NP}_a\text{)/NP}^{\text{NP}_a}}\,\mathbf{z} \quad \dfrac{\dfrac{\text{SELF-}a}{\text{NP}_a^{\text{NP}_a}}\,\textit{lex}}{\text{NP}^{\text{NP}_a}}\,\mathbf{g}(loc_1)}{\text{S/NP}_a}\,f.a.}{\text{S}}\,f.a.$$

7.3.3 A brief assurance about SELF

Thus far, for simplicity we have been assuming that SELF$_i$ is synonymous with IX$_i$ — both are of category $\text{NP}_i^{\text{NP}_i}$ and denote the identity function. However, SELF differs from IX in the property that it must be locally bound (a property commonly called Condition A in Binding Theory). Szabolcsi (1987) accounts for this by analyzing reflexives are duplicators, with the lexical entry $\langle$(S/NP)/((S/NP)/NP), $\lambda Rx.R(x)(x)\rangle$.

We can easily extend our analysis to encode this insight: we simply define SELF$_i$ as in (72). An example derivation is given in (73).

(72) SELF$_i$ $=$ $\langle$ (S/NP$_i$)/((S/NP$_i$)/NP$_i$) , $\lambda Rx.R(x)(x)$ $\rangle$

(73) JOHN$_a$ LIKE SELF-a.

$$\dfrac{\dfrac{\text{JOHN}_a}{\text{NP}_a}\,\textit{lex} \quad \dfrac{\dfrac{\dfrac{\dfrac{\text{LIKE}}{\text{(S/NP)/NP}}\,\textit{lex}}{\text{(S/NP}_a\text{)/NP}}\,\mathbf{g}(loc'_1)}{\text{(S/NP}_a\text{)/NP}_a}\,loc'_1 \quad \dfrac{\text{SELF-}a}{\text{(S/NP}_a\text{)/((S/NP}_a\text{)/NP}_a\text{)}}\,\textit{lex}}{\text{S/NP}_a}\,f.a.}{\text{S}}\,f.a.$$

8 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

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

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

a.	JOHN_a	=	$\langle$	NP_a	,	j	$\rangle$
b.	JOHN	=	$\langle$	NP_0	,	j	$\rangle$
c.	IX-a	=	$\langle$	$\text{NP}_a^{\text{NP}_a}$	,	$\lambda x.x$	$\rangle$
d.	SELF-a	=	$\langle$	$\text{NP}_a^{\text{NP}_a}$	,	$\lambda x.x$	$\rangle$
e.	LIKE	=	$\langle$	(S/NP)/NP	,	$\lambda xy.\text{like}'(x)(y)$	$\rangle$
f.	THINK	=	$\langle$	(S/NP)/S	,	$\lambda py.\text{think}'(p)(y)$	$\rangle$
g.	SEE_a	=	$\langle$	$(\text{S/NP})/\text{NP}_a$	,	$\lambda xy.\text{see}'(x)(y)$	$\rangle$
h.	$_a\text{HELP}_b$	=	$\langle$	$(\text{S/NP}_a)/\text{NP}_b$	,	$\lambda xy.\text{help}'(x)(y)$	$\rangle$

(76) *Locus underspecification deductions on nouns and verbs (loc):*

a. $\text{loc}_1 = \langle \; \text{NP/NP}_a \; , \; \lambda x.x \; \rangle$

b. $\text{loc}_2 = \langle \; \text{NP}_a/\text{NP}_0 \; , \; \lambda x.x \; \rangle$

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

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

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

(78) *Definitions of category and type lifting:*

a. $\text{Lift} = \langle \; \text{(A/(A/B))/B} \; , \; \lambda x f.f(x) \; \rangle$

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

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

Appendix B: Derivations of complex underspecification combinators

(80) – (82) give derivations of the complex combinators presented in Section 7.2.1. (83) shows that the deduction in (81) follows without the Lift operator.

(80) $(\mathbf{g}' \; loc) = \text{NP}^C/\text{NP}_i^C$

$$\dfrac{\dfrac{\mathbf{g}'}{(\text{NP}^C/\text{NP}_i^C)(\text{NP/NP}_i)} \qquad \dfrac{loc}{\text{NP/NP}_i}}{\text{NP}^C/\text{NP}_i^C}$$

(81) $((\mathbf{g}(Lift\; loc))\; \mathbf{g}) = (\text{A/NP}_i)\text{/(A/NP)}$

$$\dfrac{\dfrac{\dfrac{\mathbf{g}}{((\alpha/\gamma)/(\beta/\gamma))/(\alpha/\beta)} \qquad \dfrac{\dfrac{Lift}{(\alpha/\beta)/\delta} \quad \dfrac{loc}{\delta}}{\alpha/\beta}}{(\alpha/\gamma)/(\beta/\gamma)} \qquad \dfrac{\mathbf{g}}{\beta/\gamma}}{\alpha/\gamma = (\text{A/NP}_i)\text{/(A/NP)}}$$

where:

$\alpha = (\mathrm{A/NP}_i)$
$\beta = (\mathrm{A/NP}_i)/(\mathrm{NP/NP}_i)$
$\gamma = (\mathrm{A/NP})$
$\delta = (\mathrm{NP/NP}_i)$

(82) $(\mathbf{g}\ ((\mathbf{g}(\textit{Lift loc}))\ \mathbf{g})) = ((\mathrm{A/NP}_i)/\mathrm{B})/((\mathrm{A/NP})/\mathrm{B})$

$$\dfrac{\dfrac{\mathbf{g}}{(((\mathrm{A/NP}_i)/\mathrm{B})/((\mathrm{A/NP})/\mathrm{B}))/((\mathrm{A/NP}_i)/(\mathrm{A/NP}))} \quad \dfrac{\dfrac{((\mathbf{g}(\textit{Lift loc}))\mathbf{g})}{\vdots\ (81)}}{(\mathrm{A/NP}_i)/(\mathrm{A/NP})}}{((\mathrm{A/NP}_i)/\mathrm{B})/((\mathrm{A/NP})/\mathrm{B})}$$

(83) $(\mathbf{g}\ \mathrm{A/NP})\ \textit{loc}) = \mathrm{A/NP}_i$

$$\dfrac{\dfrac{\dfrac{\mathbf{g}}{((\mathrm{A/NP}_i)/(\mathrm{NP/NP}_i))/(\mathrm{A/NP})} \quad \mathrm{A/NP}}{(\mathrm{A/NP}_i)/(\mathrm{NP/NP}_i)} \quad \dfrac{\textit{loc}}{\mathrm{NP/NP}_i}}{\mathrm{A/NP}_i}$$

Appendix C: All data (with video numbers), as rated on the 7-point scale.

The table on the following page provides specific judgments for the examples in this paper.

A few notes: The point in (6) is also made by (9) and (34); the point in (9) is made by (34). The point in (4) is made by (4). Sentences (29a, b, c) are the same as (34a, b, d). Sentences (6) and (31) are the same. Sentences (9) and (36) are the same.

Signers 3 and 4 were tested by a colleague who did not use the seven-point scale; thus, these are reported as binary judgments.

	Report	Signer 1 Avg.	**Signer 1**	**Signer 2**	**Signer 3**	**Signer 4**
(2)	{✓, ✓}	{7, 7}	#447/#448 {7, 7}	#329/#331 {6, 6}		
(4)	{✓, ✓}	{7, 7}	#56/#57 {7, 7} (covariation of pronoun possible)	#56/#369 {6, 6} (covar. poss.)		
(5)	{✓, ✓}	{7, 7}	#58/#59 {7, 7} (covariation of pronoun possible)	#58/#378 {5, 5} (covar. poss.)		#58/none {*, *}
(6)	✓	7	#407b/#408 7; #474b/#475 7	See (34)		
(8)	✓	6.66	#95a/#98 7; #95a/#476 7; #105a/#106 6 (covariation of 'OTHER' possible)	#424b/#425 7 (*not* poss.)		
(8) with EACH instead of ALL		7	#477a/#478 7; #480a/#481 7 (covariation of 'OTHER' possible		#480a/none ✓ (*not* poss.)	
(9)	✓	7	#621/#622 7	See (34)		
(i)	{✓, ✓}	{7, 7}	#632/#633 {7, 7}			
(ii)	{✓, ✓}	{7, 7}	#634/#635 {7, 7}			
(21)	✓	7	#517/#518 7			
(23)	✓	7	#66a/#67 7			
(24)	✓	7	#512a/#513 7; #532a/#533 7; #532a/#594 7			
(27)	✓	6	#63/#65 6; #618b/#619 6; #403b/#404 6			
(28)	*	4	#618a/#619 4			
(34)	✓	7	#0/#1, 2 7; #854/#855 7 (all four readings possible; fine-grained judgments in paper.)	#0/#388 7 (all poss.)		
(43:a, b, c)	(✓, *, ✓)	(6.75, 2.75, 6)	#495/#496 (7, 4, 7); #498/#499 (7, 2, 5); #495/#636 (7, 3, 7); #498/#637 (6, 2, 5)			
(43:a, d, e)	(✓, *, ✓)	(7, 3.5, 6.5)	#500/#501 (7, 3, 7); #500/#638 (7, 4, 6)			

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