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A Combinatory Categorial Grammar of a Fragment of American Sign Language[1]

TONY WRIGHT

This project is an implementation of a Combinatory Categorial Grammar (CCG) (Steedman 2000) of a fragment of American Sign Language (ASL), providing coverage for a few of the more interesting aspects of ASL syntax and morphology, including multiple embeddings of topic-comment structures and spatial-path morphology to express thematic relations. The analysis presented here was implemented in the OpenCCG natural language processing library.

1 American Sign Language and CCG

ASL is a natural signed language; that is, it is a language which emerged naturally out of the communicative interactions of deaf people in the United States and Canada over roughly the past 200 years. From the standpoint of research into computational implementations of syntactic frameworks, ASL and signed languages in general are greatly under-represented. This project represents an attempt to implement a range of syntactic and morphological phenomena in ASL using OpenCCG. The sentences used as data for this

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project are of a well-attested, high-occurrence type which are well-known and documented in such publications as Stokoe (1960), Liddell (1980) and Aarons (1994). A basic topic-comment structure is responsible for much of the complexity and for many long-distance dependencies in ASL syntax.

CCG is a grammar formalism which assigns categories to lexical items. Categories may be *atomic*, analogous to part-of-speech labels, or functions from categories to categories (Steedman & Baldridge, 2003). A simple example from English will illustrate:

(1)
Mary	dances.
NP	S\NP
----------<	
S	

In example (1), *Mary*, of category NP, serves as input to the function *dances*, of category S\NP to yield category S, a sentence. The slash notation used in the function S\NP indicates, with a backward slash, that the function yields an S when it finds an NP to the left. In this notation, the output of the function is always to the left of the slash, and the argument the function seeks is to the left. A forward slash used in a function indicates that the function seeks its argument to the right. The line between the lexical categories and the output, with the left-facing arrow, represents CCG's rule of backward functional application, stating simply that a function may combine with an appropriate category on the left to yield its output. Other CCG rules used in this grammar are as follows (Steedman & Baldridge 2003):

(2) Functional application: X/Y Y → X "An X-outputting function seeking category Y to the right, and finding one, yields category X."

(3) Composition: X/Y Y/Z → X/Z "Category X/Y and category Y/Z can be combined into a category X/Z."

(4) Type Raising[2]: X → T/(T\X) "Category X may be converted into category T/(T\X)."

[2] Steedman & Baldridge (2003) note that *T* here is a "metavariable over categories" (p. 16). The specific type raising rule for this analysis will be NP → $S_{IP}/(S_{IP}\backslash NP)$.

In these rules, X, Y and T are variables for category labels. Other special rules used in this analysis will be introduced below.

1.2 Intransitives

The current analysis uses the type $S_{IP}\backslash NP$ for intransitive verbs such as SLEEP, SNEEZE, and WALK[3]. A sample derivation is shown below:

(5) JOHN — SLEEP
NP — $S_{IP}\backslash NP$
----------<
S_{IP}
John is sleeping.[4]

1.3 Transitives

Simple ASL transitive verbs, like intransitives, operate very much like their English counterparts. The type $(S_{IP}\backslash NP)/NP$ is used for the transitive verbs SEE, HAVE, HIT and LIKE. A sample derivation follows:

(6) JOHN — LIKE — MARY
NP — $(S_{IP}\backslash NP)/NP$ — NP
----------> (LIKE + MARY)
$(S_{IP}\backslash NP)$
----------< (JOHN + VP)
S_{IP}
John likes Mary.

1.4 Topic fronting

The phenomenon of topic fronting is responsible for many complex syntactic constructions in ASL. Topic fronting involves a sentence-initial

[3] I follow in this paper the widespread convention of representing ASL signs with what is called a "gloss," i.e., the nearest English word equivalent in all caps.
[4] As ASL is a tenseless language, time reference is often established via temporal adverbs, such as TODAY, YESTERDAY, etc. There is no tense marking on ASL verbs; they are, however, often marked for aspect.

topic phrase followed by a comment phrase, with accompanying non-manual markers and sometimes a slight upper body shift to distinguish each. [5] A special type-changing rule is used here for topic nouns, the Topic Rule: NPt => $S_{CP}/(S_{IP}|NP)$[6]. The category NPt represents the standard NP linked with the non-manual topic morphology. Item (7) below shows a derivation for a representative topic-fronted sentence involving object extraction:

(7) MARY$_t$ JOHN LIKE
NP$_t$ NP $(S_{IP}\backslash NP)/NP$
------TOPIC --->T
$S_{CP}/(S_{IP}|NP)$ $S_{IP}/(S_{IP}\backslash NP)$
----------->B
S_{IP}/NP
----------->
S_{CP}

Mary, John likes. (i.e., *You know Mary? John likes her.*)

In (8) below, the lexical item SHIFT, of category (NPt \ NPt)/NPt, is used to link constituents of the topic phrase into one topic NP. SHIFT is not a null element, but a phonologically-real non-manual marker[7]. The effect of SHIFT and topicalized nouns used together is analogous to NP relativization in English.

(8) MAN$_t$ SHIFT TIE$_t$ BLUE MARY LIKE
NP$_t$ $(NP_t\backslash NP_t)/NP_t$ NP$_t$ $NP_t\backslash NP_t$ NP $(S_{IP}\backslash NP)/NP$
----------< ---->T
NP_t $S_{IP}/(S_{IP}\backslash NP)$
----------> ----------->B
$NP_t\backslash NP_t$ S_{IP}/NP
----------<
NP_t
---------TOPIC
$S_{CP}/(S_{IP}/NP)$
---------->

[5] The non-manual markers for the topic phrase include a slight sideways tilt of the head and raised eyebrows. Non-manual markers for the comment phrase include head nodding (for affirmative comments) and a head shake (for negation of the comment phrase) coupled with eyebrow lowering to neutral position.

[6] Here the vertical slash, '|', in $(S_{IP}|NP)$ indicates that this function may seek its argument to either the left or the right. The author would like to thank Jason Baldridge for suggesting this particular form of the rule, as well as the form of the ditransitive verb category.

[7] This marker involves a slight shift of the torso, and it often sets apart items in a list or series.

S_{CP}

You know the man with the blue tie? Mary likes him.

Any number of complex topic NP's of the type TIE_t BLUE can intervene between the preposed object and the comment phrase (as shown in, e.g. (9), below) with the correct semantic results.

(9) MAN_t SHIFT TIE_t BLUE SHIFT HAT_t NEW MARY LIKE
You know the man with the blue tie and the new hat? Mary likes him.

The examples of topic shift so far have involved object shift topicalization. Subject topicalization is also possible, as when then the subject of a sentence receives intonational prominence for reasons pertaining to focus:

(10)

$\underline{MAN_t}$	SHIFT	$\underline{TIE_t}$	BLUE	LIKE	MARY
NP_t	$(NP_t \backslash NP_t)/NP_t$	NP_t	$\underline{NP_t \backslash NP_t}$	$(S_{IP}\backslash NP)/NP$	NP
			----------<	---------->	
			NP_t	$S\backslash NP$	
		---------->			
		$NP_t \backslash NP_t$			
----------<					
NP_t					
------TOPIC					
$S_{CP}/(S_{IP}\|NP)$					
---------->					
S_{CP}					

You know the man with the blue tie? He likes Mary.

Here, too, sentences like (11) on the analogy of (9), in which any number of intervening topic NP's occur between the topicalized subject and verb can be handled by the current analysis:

(11) MAN_t SHIFT TIE_t BLUE SHIFT HAT_t NEW LIKE MARY
You know the man with the blue tie and the new hat? He likes Mary.

1.5 Ditransitives

Ditransitives in ASL involve fronting of one of the three arguments of the verb[8]. This fronted element can be the subject, object or recipient. The type ((S\NP)/NP)/NP is used for ditransitive verbs such as GIVE and SHOW. A sample derivation involving object fronting is shown in (12)[9]:

(12)

BOOKt	JOHN	$_3$GIVE$_4$	MARY
NPt	NP	((S\NP)/NP)/NP	NP
-----TOP	------- T	---------->	
$S_{CP}/(S_{IP}\|NP)$	$S_{IP}/(S_{IP}\backslash NP)$	$(S_{IP}\backslash NP)/NP$	
	----------B		
	S_{IP}/NP		
---------->			
S_{CP}			

This derivation as implemented in OpenCCG represents the arguments of the verb as Arg1, Arg2, Arg3. The grammar leaves the arguments of the verbs unspecified here with respect to thematic role. One way to make the correct thematic associations would be to have the semantic arguments in a multiset. These arguments could be associated with the correct syntactic element via the unambiguous subject/object marking on the verb associated with ditransitives. The tendency of some ASL verbs--especially ditransitives--to mark subject and object relations via the paths in physical space which they traverse will be discussed in section 2 below.

1.6 Sentential Complements

Sentential complement constructions in ASL employ the same mechanism of topicalization familiar from the discussion of object shift and ditransitives above. In this case, an entire sentence is topicalized (i.e., it bears the non-manual topic features discussed in section 1.4) and serves as the argument for a sentential complement verb such as KNOW, BELIEVE, THINK, etc. As with other topic constructions, these can be embedded iteratively to produce sentences such as those shown in (13), (14) and (15). Topicalized clauses are formed by special topicalized verbs such as LIKE$_t$, of type $(S_{CP}\backslash NP_t)/NP_t$). These verbs carry topic non-manual marking as do

[8] Whether or not this fronting is obligatory is a matter about which intuitions may vary. If so, the category for ditransitives could be modified to require a topicalized sentence-initial NP argument, thus ruling out *in situ* direct objects.

[9] The subscripted numbers on the verb $_3$GIVE$_4$ serve represent agreement of the verb with spatial loci. This is explained fully in section 2.1.

their NP_t arguments, producing a kind of embedded clause marked by topic non-manual features throughout. The sentence-final matrix clause lacks topic marking. The sentential complement verbs have the category $(S_{IP}\backslash S_{CP})\backslash NP$.

(13)

JOHN$_t$	LIKE$_t$	MARY$_t$	I	BELIEVE
NP_t	$(S_{CP}\backslash NP_t)/NP_t$	NP_t	NP	$(S_{IP}\backslash S_{CP})\backslash NP$
	---------->		----------<	
	$S_{CP}\backslash NP_t$		$S_{IP}\backslash S_{CP}$	
----------<				
S_{CP}				
----------<				
S_{IP}				

I believe John likes Mary.

(14) JOHN LIKE MARY, I BELIEVE, YOU KNOW[10]
You know I believe John likes Mary.

(15) JOHN LIKE MARY, I BELIEVE, YOU KNOW, MAN THINK
The man thinks you know I believe John likes Mary.

This analysis handles these (in principle unlimited) sequences of embedded clauses followed by a single matrix clause, and the semantic relations between the constituent clauses, quite well.

1.7 Coordination

Sentences of the type:

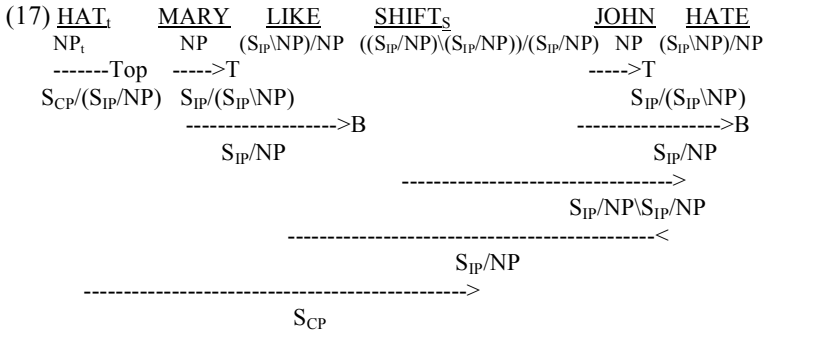
(16) HAT_t MARY LIKE $SHIFT_S$ JOHN HATE
Mary likes and John hates the hat.

are handled by using another SHIFT-type lexical item similar to the one described in section 1.4 above, $SHIFT_S$, of category $((S_{IP}/NP)\backslash(S_{IP}/NP))/(S_{IP}/NP)$[11]. A derivation of (16) is shown below:

[10] The commas in (14) and (15) are used here for clarity of exposition, but should be removed before attempting to analyze the sentences in OpenCCG.

[11] Reviewer Mark Steedman has suggested that the SHIFT category could be generalized to all coordinating categories by using an X variable and that

(17)



It is worth noting that this account of (17), a construction whose analysis is far from straightforward in many grammatical frameworks, falls naturally out of the categories assigned to lexical items in a CCG. Another attractive feature of this analysis is the grammatical status it assigns to non-manual features such as body shift. This is consistent with much recent work suggesting an important grammatical status for non-manual markers in general.

2 Spatial-Path Morphology

ASL, like most known signed languages, has a system of expressing thematic relations such as *agent, patient, recipient*, etc., through the use of spatial loci corresponding to the actual physical locations of referents which are present in the discourse context. Non-present referents are assigned to spatial loci and retain these locations for the duration of the discourse.

To give an example: suppose that a signer is narrating a story which has three principal characters, one of which is present, *John*, and two of which are not present in the discourse context, *Fred* and *Mary*. The signer will refer to *John* by pointing to his actual physical location. He or she will refer to *Fred* and *Mary* by choosing unoccupied loci in space and indicating the referent of each locus at the beginning of the discourse. All participants in the discourse will keep track of these loci and to whom or what they refer

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Jason Baldridge's * slash modality could be implemented to enforce constraints on extraction from coordination by modifying the $SHIFT_S$ thusly: (X_* X)/* X.

and will use them referentially as well in their conversational turns. Figure 1 shows these relationships.

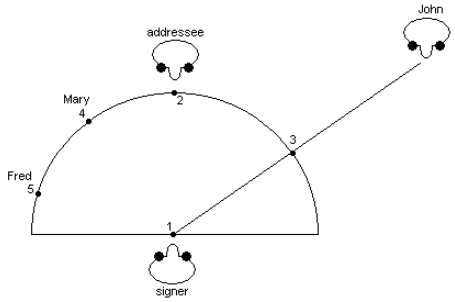

Fig. 1

Figure 1 shows a very simplified modification of a system of spatial vectors to represent the signing space first developed by Liddell and Johnson (1989). The space closest to the signer's body is designated as locus (1). Locus (2) represents the addressee. Locus (3) in this case represents a physically-present non-addresee, 'John.' Non-present referents' loci are established by a more-or-less arbitrary choice on the part of the signer, in this case (4) and (5) for 'Fred' and 'Mary,' respectively.

What role do the spatial loci play in an ASL discourse? As already noted, they may be referenced with a pointing gesture. This serves much the same role as a pronoun like *I, you,* or *she* in English. The loci also play a role in verb agreement. For the type of verb which will be most relevant to this discussion, verbs which we call *directional*, the relationship between the source and goal (or agent and patient, respectively) of a verb is represented by a path of movement which the verb's handshape traverses from the locus of the source to the locus of the goal. Item (18) is an example involving the entities mentioned in Figure 1:

(18) TIE_t MARY $_4GIVE_5$ FRED[12].
Mary gave Fred a tie.

[12] The numerical subscripts "4" and "5" in $_4GIVE_5$ refer to the starting and ending loci on the verb GIVE. I follow this practice throughout this paper.

The handshape for the verb GIVE travels along a path originating at locus (4) and ending at locus (5). Actually mentioning Mary or Fred's name is not necessary if their locations have been previously established, so that an equivalent sentence to (18) would be:

(19) $TIE_{t\ 4}GIVE_5$

2.1 Spatial Loci and Agreement Features

The current implementation includes the four loci mentioned above, representing these as pronouns linked to the feature structure ID for nouns. These loci will be referred to by the numbers given in Figure 1 (minus locus (5), which is not used in the grammar). Loci (2), (3) and (4) could be located anywhere on the arc in an actual discourse, provided they are distinguishable. Each locus is represented by two lexical items, one for a *source* locus and one for a *goal* locus to serve as arguments for a verb. The lexical items used to refer to loci (1), (2), (3) and (4), respectively, are I, YOU, THIRD, FOURTH, each subscripted with an "s" or "g" depending on whether the locus is the source or goal argument of the verb. Hence YOU_s represents locus (2) in its function as a second-person pronoun and as a thematic *source*, and $THIRD_g$ represents locus (3) as a *goal*.

Fully-directional verbs are represented using the category ((S\ NP)/ NP[source])/ NP[goal], which is the category for ditransitives such as GIVE and SHOW. Some example sentences follow:

(20a) $CAKE_t\ I_{s\ 1}GIVE_2\ YOU_g$.
I'll give you the cake.

(20b) *$CAKE_t\ I_{s\ 2}GIVE_1\ YOU_g$.

In the grammatical (20a), the *source*-locus features on the verbs match the loci represented by the lexical items to the left of the verb, and the *goal*-locus features on the verbs match the loci represented by the lexical items to the right of the verb. In the ungrammatical/unacceptable (20b), the locus features on the verbs do not match the adjacent loci.

3 Conclusion

The algorithmic rigor of a CCG and its freedom from controversial theoretical baggage can cause issues to arise which might have gone unnoticed in a less explicit formalism, or obscured by tentative, theory-laden constructs. One issue which became salient in the implementation of this grammar, and which may form the basis for future investigations, is an apparent asymmetry in the types of judgments such a grammar can make in the presence and absence of overt pronouns. Because the analysis presented here represents the spatial loci as independent lexical items which must match the agreement features of verbs, the grammar can evaluate sentences which contain no indexical points for verb-locus agreement in the absence of pragmatic information. This is important for evaluating sentences which contain redundant indexical pointing to loci whose referent has been previously established in the discourse (this redundant pointing can occur for reasons of focus or emphasis). This accords with the view of Meier (2002) who maintains, contra Liddell (2000), that the spatial loci have a grammatical, and not merely a pragmatic status.

In this paper I have presented an initial lexicon providing an analysis of several non-trivial aspects of ASL syntax with a special focus on complex topic-comment structures and the way in which topic non-manual morphology can be incorporated as lexical items in a CCG analysis. This is consistent with current trends in research concerning the grammatical status of non-manual markers.

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