A Lexicon for Translation of American Sign Language to English

by

Robbin Nicole Chapman

Submitted to the Department of Electrical Engineering and Computer Science
in partial fulfillment of the requirements for the degree of

Master of Science in Computer Science and Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

March 1997
[June 1999]

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Abstract

A new method is presented for computer translation of American Sign Language (ASL) to English by exploiting ASL morphological properties. A feature-based ASL lexicon is developed, referenced by manual and non-manual sign information. Manually produced sign segments (phonemes) consist of *sig* (movement), *tab* (location), *dez* (handshape), and *ori* (hand orientation). Non-manually produced signals consist of specific facial and body configurations. A camera captures the sign and segments the image into its morphological properties. Image segments are analyzed and values are assigned to the morpheme (*sig, tab, dez, ori, etc.*). These values are stored in a data structure which is referenced during lexical search. The first search key is *sig*, the most recognizable sign feature, followed by the other sign morphemes, as necessary, until a single lexical entry can be identified. Non-manual segments convey additional linguistic information to the output string, which is parsed and formatted for use in a universal translator program. This method relieves the vision system of responsibility for identifying the sign from a complex visual image sequence. Instead, the vision system processes smaller, less complex image segments and passes this information to the search routines.

Thesis Supervisor: Robert C. Berwick
Title: Professor of Computer Science and Engineering and Computational Linguistics

Acknowledgments

I must first and foremost thank my thesis advisor, Professor Robert C. Berwick, for his guidance and support throughout this project, and for giving me the opportunity and the space to try something new. I send thanks and love to my family, who support me in everything I do, especially my grandmothers, Mamie Turner and Mary Ella Pritchett, my mom, Laura Chapman, my sisters, Verlina Edwards and April Chapman, my aunts, Ella Dunn and Grace Tracy, my favorite cousin, John Alston, and an assortment of other relatives. Thumbs up to my colleagues at NASA's Kennedy Space Center, Florida, especially Howard Levine, Sally Litherland, Tom Dreschel, Irene Long, Mimi Shao, and Dave Chapman. We've been through nail-biting launches, heartbreaking scrubs, and hair-tearing flight design challenges and still manage to remember why we love working in space science. I owe a great debt to the Space Life Sciences Training Program, its Director, Dr. Carl B. Goodman, and former Director, Dr. Linda Chamberlain, for the opportunity to be what I've always dreamed of. Back at MIT, my thanks to the Graduate Education Office staff, especially Deans Ike Colbert and Margo Tyler, for their help and encouragement, and the EECS Graduate Office staff for looking out for me. Props to Clarence Williams, Assistant to the President, for his kindness and lessons on negotiating MIT. Back at the AI Lab, I'd like to thank Gina Levow, Nicole Love, Latanya Sweeney and Eric Brittain for their insightful discussions and life saving above and beyond the call of duty. As for my dear friends and sisters in the struggle, Judy Jones, Deirdre Lawrence, Catherine Reid, and Mary Ni, I send hugs to you all. I thank you powerful women for helping me make this journey with dignity and grace. To Don Brunson, for showing me that perseverance wins, every time. To Larry Sass, who taught me the difference between problem setting and problem solving; a critical distinction often overlooked. Regards to my friends in the Black Graduate Student Association and Color Creation. A special shout-out to my students at New House. You're the best! To the Housemasters, Professor John Essigmann, Dr. Ellen Essigmann, Amy, and Nolan, thanks from the bottom of my heart. You've treated me like a true member of your family, so I now consider you a member of mine! Last, and most important, I want to thank my mentor and friend, Dr. Theodore Raphan, of the Institute of Neural and Intelligent Systems at Brooklyn College and Mt. Sanai Hospital, New York. Ted, you embody the true spirit of discovery and skepticism! You've showed me what being a scientist really means and working with you has led me to my calling in life. I will never be able to thank you enough.

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Chapter 1

Introduction

Natural Language Processing has served well as a translator methodology for spoken languages. The challenge, therefore, is to examine non-conventional uses for these translation techniques. My work attempts to develop a spatial lexicon to be used for translation between a spoken and visual communication systems, namely English and American Sign Language (ASL). This is a challenge because of the differing natures of spoken and visual languages. Spoken languages are linear, this constraint inherent in their production. We hear the phenomes of a word as a linear sequence, whereas sign language phenomes (the sign's movement, handshape, location, etc.) are generally expressed in a non-linear fashion. Other differences such as lack of articles, modifier placement, and multi-part signs add up to a lack of isomorphism between ASL and English. For this reason, the standard lexical mapping used for translation between spoken languages is inadequate translation between a gestural and a verbal language, as this type of translation will involve more than a simple mapping of sign to English word.

1.1 Overview

My goal is to develop a lexicon that better represents those linguistic features specific to the signed word and describe a method to use this lexicon in the translation process. The sign is acquired using a camera system. A segment identification program assigns values to the sign components and then lexical searches keyed to these values are performed until a single lexical entry is identified. The word associated with each sign and any non-manual linguistic data are appended to a string which is later parsed according to ASL grammar. The parsed string is input to a universal translator program and the resultant output is directed to audio speakers.

1.2 Example

A sign is generally described by four parameters, *tab*, *dez*, *sig*, and *ori*. *Tab* refers to the *location* where the sign is made with respect to the signer's body. *Dez* indicates the *handshape(s)*. *Sig* describes the *movement* involved in producing the sign. *Ori* shows *orientation*, indicating which part of the hand points toward the ground. As mentioned in the overview, the camera system captures the sign. This image is segmented and assigned ASL morpheme values. See Chapter Four for manual data structure details. If no value can be found above the minimum threshold value, then a wild card value, *, is stored in the *sig* field. This segment identification and value assignment is done for each morpheme, in turn. Once the manual data structure is loaded, values for the combinations of non-manual signals are assigned. For example, the non-manual signal for distant-future adverbial is puffed cheeks. If puffed cheeks image information has been captured, then the cheeks field of the non-manual data structure is given the value 'puffed' and the corresponding non-manual label, distant-future-adv, is appended to the output string. Some non-manual signals are singular, meaning they alone indicate some piece of linguistic information. Other non-manual signals convey linguistic information when considered in combination with each other.

Processing

The lexicon format developed for ASL is similar to the one developed by Sandiway Fong for the Pappi Principles and Parameters Parser[Fon91], but is specifically structured to accommodate ASL features. The lexical entry format is:

```
entry(word,c,
MF[sig(dom[],weak[]), tab(dom[],weak[]), dez(dom[],weak[]),
ori(dom[],weak[]), hands((1,2),sym(+/-)), freq(+/-), rest(+/-),
contact((+/-),(what,how,where)], NMF[eye(+/-), cheeks[],
brow[], tongue(+/-), nose[], mouth[], head[]);
```

Non-manual information is extracted from the image sample. Next, the sign segments are assigned values using hidden markov models for signal dissemination, followed by a word search keyed to a particular morpheme value for each sign feature. A final lexical candidate is appended to the search string. For example, the ASL phrase, "In the distant future, he will not buy a house," utilizes manual and non-manual signals and involves pronoun indexing via pointing[1]. The non-manual signals, which provide the linguistic information about tense and negation in this example, are important to the phrase having a valid syntax. The gloss[2] for the example phrase string is:

$$\overset{\textbf{puffed cheeks}}{\overline{[distant-future\quad adverbial]}}\quad \overset{\textbf{neg}}{\overline{xi3\quad NOT\quad BUY\quad HOUSE}}.$$

This example phrase would be processed in the following manner:

[1]Pronoun indexing, which is unambiguous in ASL, is discussed in detail in Chapter Three's ASL Pronoun section.

[2]Gloss Notation: terms in [] are non-manual lexical items. Overline indicates the scope of a non-manual over a word, clause, or phrase. Bolded terms atop the overline are the non-manual signal, or a label for a particular non-manual behavior.

1. *Image is sampled. Obtain non-manual signal(s).* The non-manual signal for puffed cheeks is recorded. The value "puffed" is stored in the cheeks field of the non-manual data structure. This non-manual configuration indicates the lexical tense marker DISTANT-FUTURE-ADV. Append the text "DISTANT-FUTURE-ADV" to the output string. Check for other non-manual signals. If none are available, go on to processing manual signals.

2. *Process manual signal(s).* No manual signals recorded.

3. *Image is sampled. Obtain non-manual signal(s).* The non-manual signal for negation is recorded, a label is assigned (in this case "NEG") and appended to the output string. No other non-manual signals are available from this image sample, so go on to process manual information.

4. *Process manual signals. As mentioned earlier, extract and analyze each morpheme segment (in this case sig, tab, dez, ori, or some other manual feature) and assign a value that falls within the probabilistic threshold value for that signal. Perform lexical search and prune until a single candidate is selected or an exception marker returned. Append selection to output string. A exception marker indicates no entry was found or unresolved ambiguity exists between several candidates.* The *sig* (movement) information is extracted from the image and the signal is compared against known HMM probability distributions. If the sign falls within a minimal threshold probability of a particular distribution, the morpheme value is stored in the manual data structure. If no value can be found or a single distribution cannot be identified, a wild card value, (*), is stored in the *sig* field. This segment identification and value assignment is done for each sign morpheme (*tab, dez, ori*, etc.). The manual sign

values for this first sign are :

sig = dom[forward]

tab = dom[chest]

dez = dom[g-CL]

ori = dom[k], weak[], dom[p], weak[][3]

5. *Perform lexicon search.* The morphemes become search keys in the order that they appear in the data structure. The first search key is "forward" and the following entries are extracted from our lexicon: enthusiastic, xi3, knife, like, not.
   The next search key is "chest" and the following entries are extracted from the previous list: enthusiastic, xi3, knife, like.
   The next morpheme key is *dez* with the value "g-CL." The following entries are extracted from the previous list: xi3, knife.
   The next search key is *ori* with the values "k" and then"p" for the dominant hand. The following entry is extracted from the previous list: xi3. This single entry is appended to the output string.

6. *Image is sampled. Obtain non-manual signal(s).* The non-manual signal is processed and the NEG value is assigned. NEG already appears in the output string, so it is not appended again. No other non-manual signals are available from this sample, so go on to process manual information.

7. *Process manual signal.* The camera system segments the manual sign and assigns the values:
   sig = dom[forward]
   tab = dom[chin]

[3]The sign starts with the hand in k-orientation and ends with the hand in p-orientation. See Chapter Four for a description of possible morpheme values.

dez = dom[a-CL]

ori = dom[l]

8. *Perform lexicon search.* The search key for *sig* is "forward" and the following entries are extracted from our lexicon: enthusiastic, xi3, knife, like, not.
   The search key now becomes the *tab* value, which is "chin." The following entry is extracted from the previous list: not. This single entry is appended to the output string.

9. *Obtain non-manual signal(s).* The non-manual signal is recorded, a value is assigned (in this case "NEG"). NEG already appears in the output string, so it is not appended again. No other non-manual signals are available from this sample, so go on to process manual information.

10. *Process manual signals.* The segment values for this sign are :
    sig = dom[],weak[],dom[forward],weak[]
    tab = dom[waist],weak[waist],dom[chest],weak[waist]
    dez = dom[c-CL],weak[b-CL]
    ori = dom[b],weak[b]

11. *Perform lexicon search.* The search key value for *sig* is: "*null*,*null*,forward,*null*" and the following entries are extracted from our lexicon: he, buy
    The search key now becomes the *tab* value, which is "waist,waist,chest,waist."
    The following entry is extracted from the previous list: buy. The search is terminated and "buy" is appended to the output string.

12. *Obtain non-manual signal(s).* The non-manual signal is recorded, a value is assigned (in this case "NEG"). NEG already appears in the output string, so it is not appended again. No other

non-manual signals are available from this sample, so go on to process manual information.

13. *Process manual signal.* The camera system captures the next sign. The manual sign values are:
    sig = dom[down-right],weak[down-left],dom[down],weak[down]
    tab = dom[forehead],weak[forehead],dom[shoulder],weak[down]
    dez = dom[b-CL],weak[b-CL]
    ori = dom[p],weak,[p],dom[l],weak[r]

14. *Perform lexicon search.* The search key value for *sig* is: "down-right, down-left, down, down" and the following entry is extracted from our lexicon: house. The search is terminated and "house" is appended to the output string.

15. *Obtain non-manual signal(s).* The non-manual signal is recorded, but no values are assigned because none were associated with the non-manual signal. Go on to process manual information.

16. *Process manual signal.* The camera system captures the next sign. The manual sign values for this first sign are :
    sig = dom[],weak[]
    tab = dom[leg],weak[leg]
    dez = dom[],weak[]
    ori = dom[l],weak[r]

17. *Perform lexicon search.* The search key value for *sig* is: "*null,null*" and the following entries are extracted from our lexicon: I, book, corn, elephant, eyes, chocolate, love, love, eou. The search key now becomes the *tab* value, which is "leg,leg." The following entries are extracted from the previous list: eou. Eou is the

end-of-utterance command. It literally means 'hands at your sides' and is not the only signal used by ASL signers, but for this work we will suffice with this simple sign. The parse routine is activated.

18. *Parse output string.* The output string is parsed into its linguistic constituents using the Earley parsing algorithm. This parsed string can be used as input to a properly configured universal translator program.

The output string from the lexical search for our example phrase is:
"distant-future-adv neg xi3 buy house."
The Earley parser processes the string and outputs the following parse:

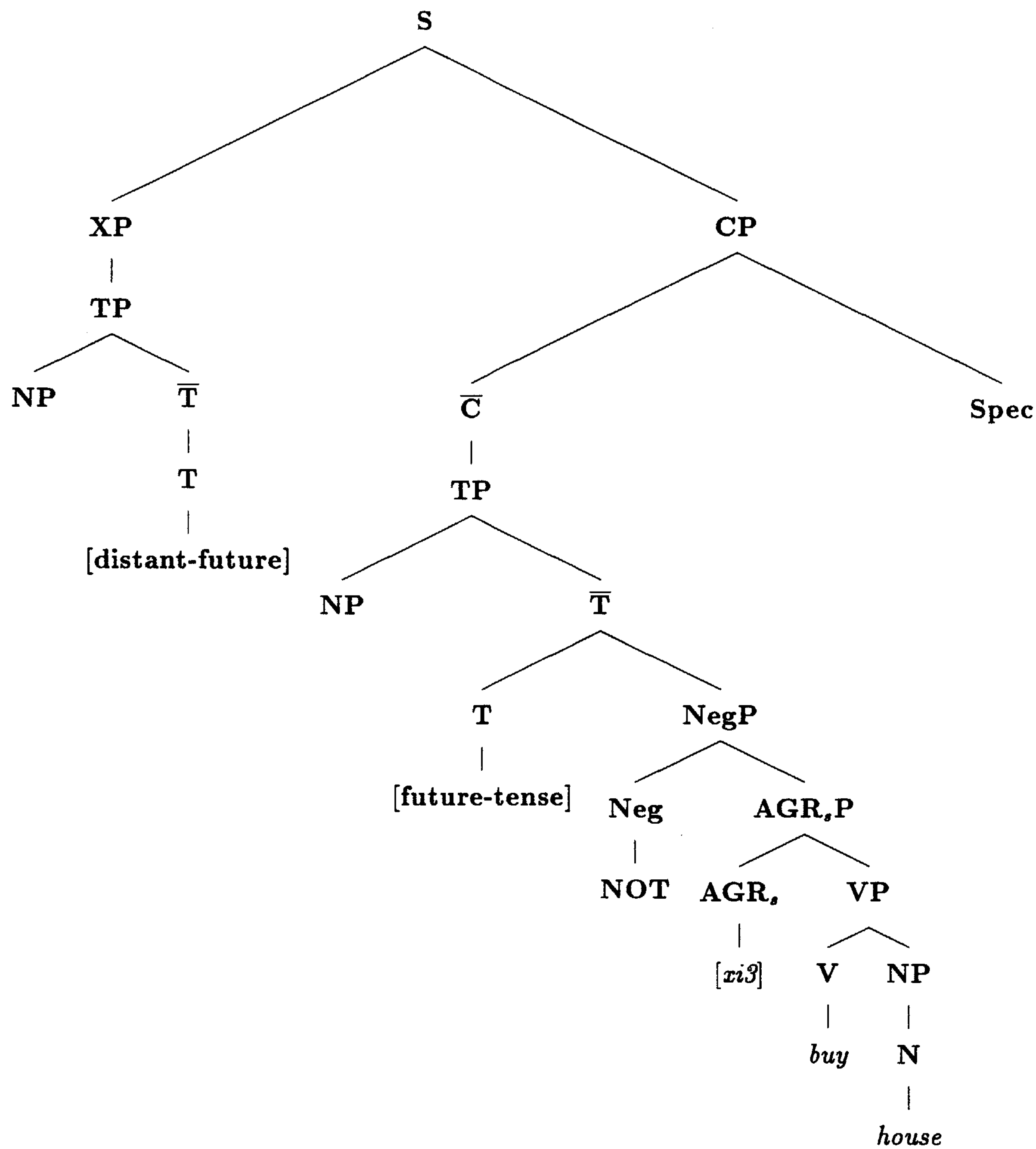
```
0  0   *DO* ==> . ROOT $
0  0   ROOT ==> . S
0  0   S ==> . LTM NV
0  0   S ==> . LTM S/NEG
0  0   S ==> . LTM ASP
0  0   S ==> . S/NEG
0  0   S ==> .
0  0   S/NEG ==> . LTM N NEG NV
0  0   S/NEG ==> . LTM NV4
0  0   ROOT ==> S .
0  0   *DO* ==> ROOT . $
1  0   S ==> LTM . NV
1  0   S ==> LTM . S/NEG
1  0   S ==> LTM . ASP
1  0   S/NEG ==> LTM . N NEG NV
```

```
1  0   S/NEG ==> LTM . NV4
1  1   S/NEG ==> . NEG NV
1  1   S/NEG ==> . NEG ASPECT NV
1  1   NV4 ==> . NEG PRO ADV VP
2  1   S/NEG ==> NEG . NV
2  1   S/NEG ==> NEG . ASPECT NV
2  1   NV4 ==> NEG . PRO ADV VP
2  2   NV ==> . NP VP
2  2   NP ==> . PRO
3  1   NV4 ==> NEG PRO . ADV VP
3  2   NP ==> PRO .
3  2   NV ==> NP . VP
3  3   VP ==> . ADV V
4  1   NV4 ==> NEG PRO ADV . VP
4  3   VP ==> ADV . V
4  4   VP ==> . N VP LTM
4  4   VP ==> . V
4  4   VP ==> . N VP
4  4   VP ==> . V ADV
4  4   VP ==> . V NP
5  3   VP ==> ADV V .
5  4   VP ==> N . VP LTM
5  4   VP ==> V .
5  4   VP ==> N . VP
5  4   VP ==> V . ADV
5  4   VP ==> V . NP
5  2   NV ==> NP VP .
5  5   VP ==> . N VP LTM
5  5   VP ==> . N VP
5  1   NV4 ==> NEG PRO ADV VP .
```

```
5  5   NP ==> . N
5  1   S/NEG ==> NEG NV .
5  0   S/NEG ==> LTM NV4 .
5  0   S ==> LTM S/NEG .
5  0   S ==> S/NEG .
5  0   ROOT ==> S .
5  0   *DO* ==> ROOT . $
6  5   VP ==> N . VP LTM
6  5   VP ==> N . VP
6  5   NP ==> N .
6  4   VP ==> V NP .
6  1   NV4 ==> NEG PRO ADV VP .
6  0   S/NEG ==> LTM NV4 .
6  0   S ==> S/NEG .
6  0   ROOT ==> S .
6  0   *DO* ==> ROOT . $
6  5   VP ==> N . VP LTM
6  5   VP ==> N . VP
6  5   NP ==> N .
6  4   VP ==> V NP .
6  1   NV4 ==> NEG PRO ADV VP .
6  0   S/NEG ==> LTM NV4 .
6  0   S ==> S/NEG .
6  0   ROOT ==> S .
6  0   *DO* ==> ROOT . $
7  0   *DO* ==> ROOT $ .

((ROOT (S (S/NEG (LTM DISTANT-FUTURE-TENSE) (NV4 (NEG NEG) (PRO XI3)
   (ADV NOT) (VP (V BUY) (NP (N HOUSE)))))))
```

This parse produces the following ASL tree:



1.3 Processing Hazards

Image feature extraction and the subsequent feature value assignment can lead to hazards that may jeopardize successful lexical search or parsing. These hazards fall under three categories:

Feature Incompleteness

This hazard involves a feature not being recognized by the system and therefore not given a value. The signs for KNIFE and ENTHUSIASTIC present an example of the possibility of feature mismatch. One of these signs may be inadvertently identified as the other by the search algorithm if non-dominant (weak) hand movement overlooked during image segment processing. While both signs have forward movement of the dominate hand, ENTHUSIASTIC also has a simultaneous backward movement of the non-dominant hand. If this feature is overlooked or misinterpreted during signal processing, the lexicon entry "knife" could mistakenly be appended to the output string instead of "enthusiastic," which is the correct entry. Knife is a noun and enthusiastic is an adverb. The parser would not be able to find a valid parse for this phrase with a noun in the adverbial position in the output string, resulting in a parse failure.

Feature Mismatch

Another processing hazard is the case of a feature being assigned an incorrect value. Feature mislabeling could occur as a result of the similarity of properties for a particular morpheme (i.e., the *sig* values [arc-forward] and [forward] are very similar). For example, if the sign GIVE, which has the label *sig*=[arc-forward], was instead assigned the label *sig*=[forward], a lexical search would find a match with the entry LIKE, which has *sig*=[forward] and shares the same *tab* as GIVE. Further processing of the remaining morphemes (*dez* and *ori*), which are not the same in both signs, would result in an exception marker being raised, indicating that no lexical entry was found. In this case, an existing lexicon entry has failed to be identified during the lexicon search because of an incorrectly labeled feature.

Too Many Matches

Another processing hazard involves the search process returning more than one entry. Usually, when several entries share the same combination of *sig, tab, dez* and *ori* values, the remaining manual features (hands, freq, rest, and contact) and any required lexical non-manual features are referenced to "break the tie." Of course, if these features are not available, possibly due to a feature incompleteness hazard, this could result in too many entries selected with no way to disambiguate them. This hazard could also be caused by the search key being set to the wild card value. Again, this could result, too many entries being selected with no way to disambiguate them. Wild cards are a provision for assigning values to image segments whose morpheme value cannot be determined. The wild card is necessary because it increases the chance of a lexicon entry being identified, even with incomplete information. In many cases, a single lexical item can still be identified, even with partial information, if some subset of its feature values is unique. An example of a wild card causing a Too Many Matches hazard is the signs TAPE, CHAIR, and TRAIN (see fig. 3-1). These signs all share the same *dez, tab* and *ori* values, with the *sig* parameter distinguishing them. If *sig* is assigned the wild card value, there would be no way to identify a single lexical entry. This would cause an exception marker to be raised, indicating that there are too many matches for the current sign image and the lexical search has failed.

1.4 Organization of Thesis

Chapter One is an introduction to this work and an examination of the issues unique to sign language machine translation. In Chapter Two, the background of ASL is presented. We take a look at ASL grammar, structure, and syntax. Chapter Three presents Kegl's sign notation as a way of capturing a sign's information and encoding of the lexicon using a structure that has been influenced by her notative system. Language constraints and particular signing behaviors are examined. In Chapter Four, the ASL lexicon is presented and a method is described for lexical search and subsequent parsing of the ASL string. Chapter Five presents a discussion of this method, survey of current research in this area, and recommendations for future studies.

Chapter 2

American Sign Language

ASL is the visual-gestural language used by deaf people in American and parts of Canada. It has origins in French Sign Language, diverging over the years to form its own syntax and structure. Being a natural human language, ASL is unique in its phonology, syntax, semantics and, of course, its use of gesture as primary mode of production. A common misconception is that ASL is mime, however, while some signs iconic are ASL word meaning is conveyed through the sign's linguistic components. A sign is generally described by four parameters, *tab*, *dez*, *sig*, and *ori*. *Tab* refers to the *location* where the sign is made with respect to the signer's body. *Dez* indicates the *handshape(s)*. *Sig* describes the *movement* involved in producing the sign. *Ori* shows *orientation*, indicating which part of the hand points toward the ground. These parameters are roughly equivalent to the phonemes of a spoken language[San89] and are usually articulated simultaneously within a given (simple) sign. An individual component, if articulated separately, would not be perceived except in combination with the other parameters. Although there are some monomorphonic signs that have two different places of articulation (or two hand configurations), within those signs there is a linear sequence of components. However, the sign must still be articulated in combination with components from the other parameters. Many universal linguistic properties of spoken language also appear in ASL, albeit through different mechanisms. Both spoken and sign languages divide words into pieces, known as morphemes, that can be used to build words. These morphemes are known as vowels and consonants. As with other languages, ASL has some valid combinations of morphemes, while other combinations produce gibberish. ASL also has many unique, language-specific characteristics due to it's modality. For example, sign language has a capacity for expressing its sub-lexical components *tab, dez, sig,* and *ori* simultaneously. Also, the signer's body provides important linguistic information through non-manual cues. Although English can convey other linguisitic information through vocal tones, body posture, and facial expression, the primary, and generally sufficient, mode of production is sound.

2.1 A Tale of Two Grammars

ASL is a hybrid of manual and non-manual features. It is therefore important to note how differently ASL and English handle their linguistic peculiarities.[Lid80] This is a brief summary of those differences. Many will be discussed further within this text.

COMPARISON OF ASL AND ENGLISH GRAMMARS

Type	American Sign Language	English
Agreement	• Object agreement more prevalent than subject agreement. • Spatial and classifier verb subject agreement is accomplished by a change in hand shape or movement.[Pad81]	• Subject-verb agreement is a syntactic constraint.
Aspect	• Usually *dez, tab* and *ori* remain the same, but *sig* changes. Signer can incorporate new information by changing the production of the sign's base form (i.e., reduplication). Under reduplication DRINK becomes DRINK-DRINK, which means keep on drinking and drinking.	• Adds new lexical items or attaches an affix to the verb.
Conjunctions	• Not explicit in ASL. Instead nouns, verbs, and adverbs are signed in sequence.[Fan83]	• Nouns, verbs, or adverbs are normally joined by a conjunctive.

Nouns	• Little or no inflectional morphology. • Locative relations are expressed as full verbs incorporating two classifiers, one for figure and one for ground.	• Prepositional phrases indicate locative relations.
Phonological Contrasts	• Has distinct phonological contrasts, including differences in handshape, number of hands used, location (in space or on the body), shape of movements, differences in hand orientation, segment duration, sign repetition, and position of stress. Non-manual features include movement of eyes and eyebrows, mouth, head, shoulders, and trunk.	• Tone/pitch changes, and vocal emphasis, add morphological information to the word.
Prefix and Suffix	• Has very few prefixes, suffixes, or particles. Instead, morphological contrasts are marked by re-duplication, feature changes, or compound formation. [GC93]	• Uses prefixes, suffixes, and particles to show morphological contrasts.
Prodrop	• A pro-drop language, allowing omission of all unstressed pronouns.[LM91] • Pronoun reference is non-ambiguous and is achieved by pointing to or looking at a referent's location in the signing space.	• Empty pro category for NULL subjects (i.e., making use of declarative sentence without a subject)

Tense	• Time and tense are expressed relative to the signer's body along a time plane. • Tense is set at the beginning of a phrase and not referred to again unless it changes. • Verbs can be inflected for a variety of temporal aspects, but not for tense.	• Tense is marked by using modal or morphological changes to the verb itself. • Tense can be context implicit (i.e. "yesterday I drove").
Topic	• Topic prominent language with topics used for a variety of different functions, including conditional and identification clauses. Topics are often stated first in the sentence and then commented on. ASL tends to first indicate what the thing is they want to talk about (topic) and then makes some statements, questions, etc., about that topic.	• All topics are explicit and topic agreement is crucial.
Wh-words	• Exist in ASL for use in questions. They do not indicate relativization.	• Exists for questions.

Word Order	• Order is meaningful in ASL.[Ste81] Many ASL sentences have structures like $S \longrightarrow X + Y$, where X is not necessarily followed by Y as may be expected, but where X and Y occur simultaneously. The ASL signs for "you like" and "like you" are as different as the same two English sentences. While both English and ASL have XY and YX ordering, ASL also has $\frac{X}{Y}$ and $\frac{Y}{X}$ ordering with the sign on top having priority over the sign on the bottom. Also, ASL exhibits SVO and SV word order, as well as word orders that are used to convey topicalization. • In a single sign, we usually see the expression of the verb and its arguments through simultaneous production.	• SVO word order with overtly marked accusative and nominative pronouns.

Verbs	• Once a point in space is established in space and associated with a noun phrase, verbs can be inflected for agreement. • Although ASL has an underlying SVO word ordering, surface ordering is free. The derivation of verbs from classifier and verbal roots is highly productive, with many verbs incorporating either one or two classifiers. The phonological handshape of the dominant hand is referred to as the *primary classifier*. It characterizes agent, instrument, or theme. Some verbs also use a *secondary classifier*, whose phonological handshape is the non-dominant (passive or weak) hand. This second handshape can be positioned at the beginning, middle or end of lexical movement. Beginning position characterizes agent or source, middle means an object that the subject or theme passes by, and end characterizes object or goal. The second classifier near the active hand for the duration of the sign characterizes an object where verb action is oriented towards the patient.	• Verbs are always inflected with strict SVO word ordering. Verbs are inflected to passive voice by addition of surface morphemes (-ed, etc.)

Verbs, cont'd	• ASL has four types of verbs: inflecting, plain (non-agreeing), spatial, and classifier[LM91]. Inflecting verbs exhibit a rich subject and object agreement morphology, which is based in movement. Agreement is obtained by changing the movement or direction of the underlying sign. Plain verbs, however, have no agreement morphology for subject or object and therefore don't change based on an object/subject.[LM91]	• Provides surface representations of concepts of time (i.e., tense and aspect).

2.2 Linguistic Properties

When discussing the physical properties of spoken languages, we refer to terms like pitch, pace, power, stress, and modulation. These same properties are conveyed in ASL through facial expression, head and body movement and space usage in relation to the signer.

2.2.1 Phonology

Phonology typically refers to the patterning of sound. In English, vowels and consonants comprise these patterns. ASL exhibits similar structure at the sub-lexical and phonological level through patterning a sign's formational units. Of course, like any other language, there are restrictions on how units are organized. Phonological distinctions are made in three ways: hand configuration, place of articulation, and movement. ASL contrasts about thirty-six different handshapes and permits many different path movement types (i.e., arc, straight, circling). In fact, movement *(sig)* is a key lexical item in the identification process, as it has been shown to lead to sign identification more quickly than the other three parameters.[Emm93]

Phonological Constraints

There are phonological constraints on sign formation that define legal motion combinations and relationships between the hands.[SK85] *Symmetry Condition* is evident in two-handed signs with both hands moving. In this case, handshape and movement specifications are identical and symmetric. *Dominance Condition* involves a two-handed sign with two different handshapes. It allows only one hand (usually the dominant one) to be moving and only six possible handshapes can be used in the non-moving (or base) position of the sign. When a sign's movement requires two points of contact with the body, there is a constraint on the possible contact combinations. Dividing the body into four major areas (head, truck, arm, and hand), only eight of sixteen possible combinations occur. Only four, involving contact in the same area, are valid.

2.2.2 Building Blocks of ASL Words and Phrases

Segments

Due to its spatial characteristics, an ASL vowel or consonant is a function of visual rather than vocal expressiveness. Individual sign segments can be looked at as hold (h) or move (m) segments. Hold segments are periods of time when articulatory features are in a steady state. Movement segments are periods of time when articulatory features are in transition from one state to another. In other words, a sign can be described by its segments. For example, the sign for Give, seen in Fig. 2-1, has three segments, hmh.

Figure 2-1: GIVE sign with three segments
Redrawn from [Ste87].

Segment Sonority

Segment sonority is defined as the intensity of contrasts between segments. In speech, contrast is marked by the open airflow, clear sound resonance, high acoustic energy, and perceptual salience.[San89] In ASL, contrast is a function of movement or lack of movement. To obtain high sonority, *movement* segments are produced with unimpeded movement, comparatively greater energy, and are perceptually salient. In contrast, *hold* segments involve little or no movement, are produced with lower energy, and perceptually less salient.

Syllables

In English, the syllable serves a variety of functions: it is the basic unit of stress, a primary unit of production and perception, a domain of phonotactic constraints, and the basic unit of timing. A correspondence between ASL and English sonority stress patterns and phonotactic constraints define the unit identified as the syllable.[San89] ASL provides emphatic stress, with stressed signs having longer and faster movement, for example a more abrupt stop at the end of the sign or a more tense handshape. Brushing, handshape changes, and location of sequences have constraints which characterize the domain of the ASL syllable. Only a limited number of valid configurations of brushing patterns and handshape changes and sequences of location can occur. Brushing involves the movement of one hand in contact with the other hand or with the body. Distribution of brushing occurs at very specific instances, with co-occurrence constraints on brushing *patterns of handshape change*, and allowed *sequences of location* within non-compound signs. Brushing is found between an initial stop and following a movement (i.e., the sign for SKILL), between two stops (i.e., the sign for ENTHUSIASTIC) or at the peak of an arcing movement (i.e., the sign for KNIFE) (Fig. 2-2.) but not between a preceding movement and a final stop. *Patterns of handshape change* are constrained in terms of the ASL syllable. A handshape can occur syllable initial and another handshape syllable final. In compound signs, two handshapes must be closely related (i.e., an extended, bent, or curled finger must involve the same set of fingers for each handshape). The constraint on allowed sequences of handshapes involves a change in one feature only. *Sequences of locations* are constrained within non-compound signs. In this case, the two locations must differ only within a single body dimension, for example:

[upper temple]	to	[lower temple]	(as in sign for HEAD)
[right nostril]	to	[left nostril]	(as in sign for FLOWER)
[under right eye]	to	[under left eye]	(as in sign for EYES).

Sequences of location differing in more than one dimension are invalid and equate to gibberish (for example, [left forehead] to [nose tip]). This is similar to syllables having certain configurations and constraints on how they can be put together. (Fig. 2-3.)

ASL Nouns and Verbs

Languages distinguish phonologically between nouns and verbs, via their inflection classes. ASL distinguishes nouns from verbs on two levels, one with the noun/verb as a purely

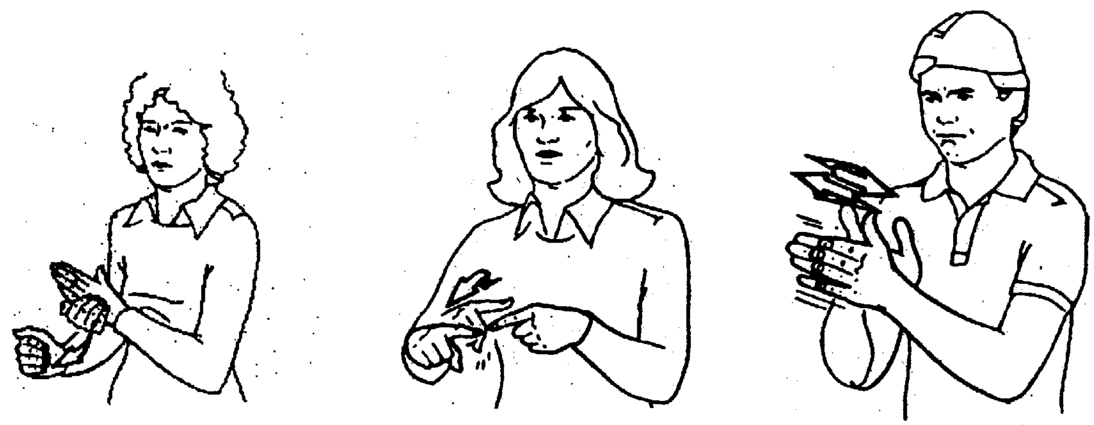


Figure 2-2: Signs for SKILL, KNIFE, and ENTHUSIASTIC
showing constraints on brushing.
Redrawn from [And93].

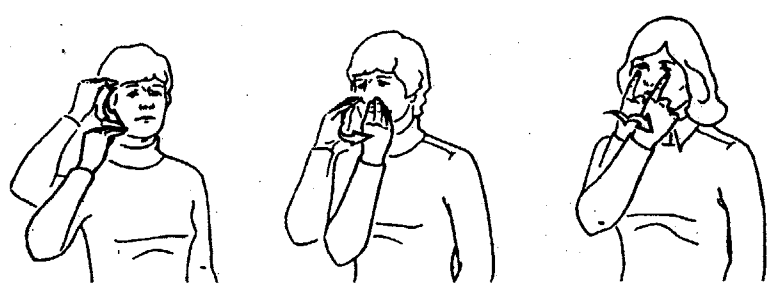


Figure 2-3: Signs for HEAD, FLOWER and EYES
demonstrating single body dimension constraints on sequences of movement.
Redrawn from [And93].

lexical item and the other with the noun/verb relation to one another.[TS76] A lexical noun or verb can occur independent of an accompanying noun or verb. For example, the noun ELEPHANT could occur with no conceptually related verb. The verb YELL can occur without a conceptually related noun. Nouns and verbs that are lexically and conceptually related in English (i.e., FISH (n) or FISH (v)) do not always share that relation in ASL. The sign for the verb FISH is different and distinct from the sign for the noun FISH (Fig. 2-4). A second type of ASL noun or verb occurs when the noun refers to an object related to a verb for the action performed on that object. In this case, the sign for the noun and the verb is the same and context determines reference to the action performed on the object (for example, CHAIR (n) and SIT (v)). In context, the sign 'SIT' refers to a chair. More importantly, variance in movement is often used in signing to distinguish between nouns and verbs that are related in form and meaning. These noun/verb pairs fall into three categories.

1. The noun and verb share formational characteristics, (i.e., some *tab, ori, dez,* and *sig*). This is seen in the noun/verb pair CHAIR/SIT.

2. Noun movement is more restricted than verb movement. There are also variances in verb movement signal duration, frequency, etc. In English, these distinctions are made by a change in a verb's form. Nouns have fewer variances in the type of movement allowed and movement style and frequency consists of smaller movements. In fact, without these distinctions many nouns and verbs would not be separate items in the lexicon. Instead, you would just have a single entry for each noun/verb pair and have to rely solely on contextual information to derive the appropriate type.

3. Noun/verb are related in meaning, with the verb expressing activity which is done on/with the noun (i.e., sit expressing an

activity performed on a chair).

Not all ASL noun/verb pairs are distinctive in their manner of production. Often, the syntactic context alone determines whether a particular sign is a noun or verb. Again, an example of this characteristic is the word "fish," which in English has only context and inflection to show whether it is a noun or verb. In ASL, some noun/verb pairs are distinguished from one another through reduplication of the base form of the noun. For example, in the noun/verb pair DECIDE/DECISION, the noun base form is repeated (DECISION-DECISION) to distinguish it from the verb form.

ASL Pronouns

ASL does not employ pronouns in quite the same way spoken languages do. Signs representing pronouns (i.e., he, she, they, we) do exist but are rarely seen. Instead, ASL uses a variety of methods including indexing, marking, and incorporation to express these relationships. There are potentially an infinite number of pronomial references that can be made, and they refer unambiguously to a specific referent. Unlike spoken languages, with ASL you will never encounter a situation such as:

John thinks he is good. (*he* is co-referential with *John*)
John thinks he is good. (*he* is not co-referential with *John*)

The pronoun itself does not indicate gender or person (i.e., first, second, or third person). Person is derived through **LOC**[1] indexing. If the pronoun is indexed with the conversant, it becomes the second person. If indexed with the **SBP** $\mathbf{LOC}_i$, then it becomes the first person. If indexed with some other position, then it becomes third person. An ASL pronoun is marked with one of two possible referential indexes, either overt or non-overt. Overt

[1]An explanation of **LOC** and **SBP** can be found in Chapter Three.

Figure 2-4: Signs for FISH (noun and verb)
Noun/verb pair that are conceptually related in English but not in ASL.
Redrawn from [Ste87].

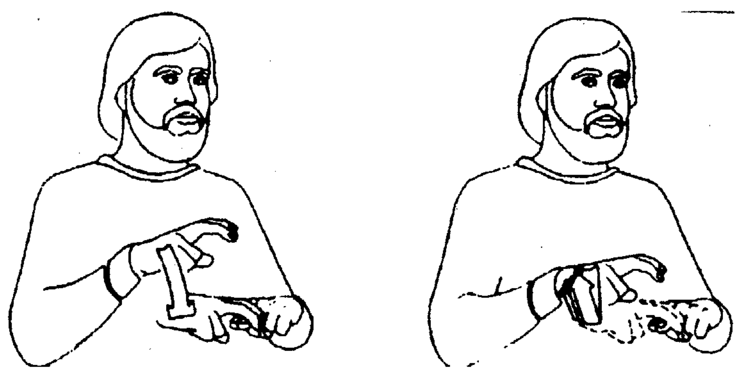


Figure 2-5: Signs for SIT and CHAIR
Either context or variance in movement distinguishes noun from verb.
Redrawn from [Ste87].

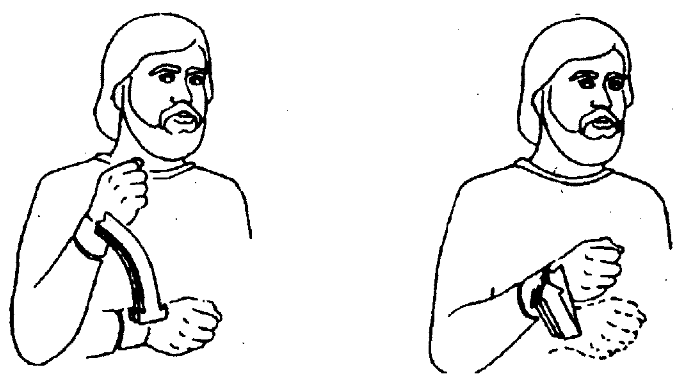


Figure 2-6: Signs for HAMMER (verb and noun)
Variance in movement distinguishes noun from verb.
Redrawn from [Ste87].

pronouns include two types, which are indicated by pointing the hand or by body movement toward positions in space. The locations in space point to the virtual locations of the referents. The body may also be used as a marker that takes on the identity of the referents. Markers have two forms: the signer's hand(s) (articulated markers) or the signer's body (body markers). When using body movement to establish the location of reference, for example, the signer can turn his body to face a particular location and sign a nominal or name in that position. That position is then understood to represent that specific referent. The signer's body may also be used as a marker, with the signer assuming the identity of the referent for that location when the signer occupies that location. Neither of these overt forms involve lexical items, but instead use spatial representation. Because a pronoun's configuration consists of at most one formatted parameter (*tab, dez, or sig*), they can be incorporated into other signs. For plurals and combinations of pronouns, the signer points in succession to the people involved, or uses a general sweeping motion encompassing a group. There are handshapes that can be pointed at individuals to reference two, three, four, or five persons. Absent references are referred to by indexing. A non-overt pronomial reference, known as employment, involves a single parameter becoming one the parameters of a sign while still maintaining its function of representing a referent.

2.2.3 Non-manual Signals

Non-manual signals are used to begin sentences, change topics, link compounds, state questions, etc. Non-manual linguistic information is conveyed through the signer's facial expression, posture, and body position. Indeed, in some cases there would be ambiguity of word understanding without the corresponding non-manual indicators. A few indicators are associated with particular lexical items; the expression occurs only while the sign is being made. For example, BITE is usually signed with a biting mouth motion and RELIEVED is signed with an exhaling burst of air. Some non-manual signals have phrasal domain and become part of the phrase grammar. The sign for RECENTLY may have one of two facial expressions, the first denoting 'recently' and the second 'just recently' (Fig. 2-8). Beyond their use in disambiguating some signs, non-manual indicators are necessary grammatical markers for relative clauses.[BP76] There are particular non-manual signals that co-occur with verb and adjective signs, and are commonly known as non-manual adverbials. For example, the tongue protruding slightly between the teeth indicates an adverbial. Also, non-manual signals can denote differences in dimensions, such as puffed cheeks for large objects, and sucked in cheeks and rounded lips for small objects occuring with verbs. However, combining a noun without the verb (such as HOUSE with puffed cheeks, to indicate a BIG HOUSE), is ungrammatical and would be confusing in conversation.

Eye Movement

Lexical information can also be derived from gaze direction. For example, the sign SEARCH requires a searching movement with the eyes. The signs RIVER and MOUNTAIN are visually indexed by gazing toward the area shaped by the hands. As a modifier, the relative length of a subject can be indicated via the eyes. For example, the eyes follow the hands for SHORT ROAD but are always ahead of the hand movements for LONG ROAD. Pronominal references using gaze direction toward spatial referents function similarly to finger pointing (manual indexing). A constituent's boundary is marked by looking away and then back when a new constituent is introduced. Finally, a lengthy eye closure provides emphasis. These movements occur with manual signs, mostly during noun or verb modifiers.

Facial Movement

Facial expressions provide a small set of lexical items and is often used to disambiguate among many manual signs. For example, NOT-YET and LATE use the same manual sign with differing facial expressions to differentiate them. Modifiers occur with manual nouns or verbs. For example, BIG TREE can be signed with the manual sign TREE and several non-manual behaviors occurring simultaneously. The affirmative "yeah," is indicated by nose twitching, without any manual sign. Negation is signaled via facial frown, lower brows, nose

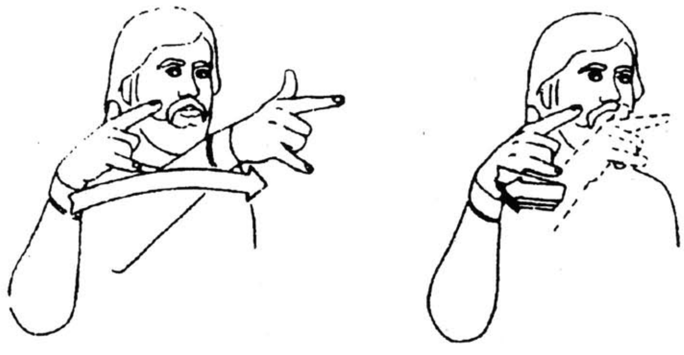


Figure 2-7: Signs for FLY (verb) and AIRPLANE (noun)
Redrawn from [Ste87].

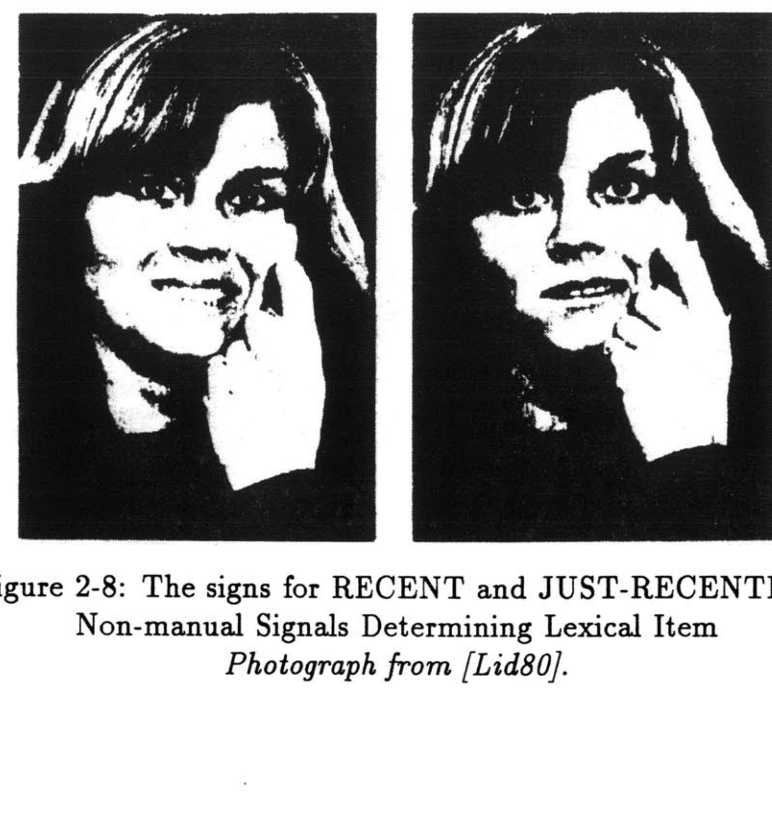


Figure 2-8: The signs for RECENT and JUST-RECENTLY
Non-manual Signals Determining Lexical Item
Photograph from [Lid80].

wrinkling, or sticking out the tongue. While there are manual signs for NO and NOT, their use varies and they are usually accompanied by a non-manual negation signal. Questions are indicated by a raised brow, retracted eyelids, and head nods and shakes.[Lid80]

2.2.4 Grammar and Syntax

Clearly, non-manual signals are important in ASL. Interestingly enough, in ASL it is the non-manual signals that determine sentence type, not the word order, as in English. Non-manual signals can have differing coverage over the sign phrase. These coverings may occur at the lexical, phrasal, or clausal level depending on the signal. Individual words which require non-manual signals (i.e., the sign BITE, which is accompanied by a biting motion, or 'ba' mouth-jaw movement with the sign GIVE-IN) utilize a signal that only has scope over the lexical item. Non-manual signals that are part of the phrasal grammar usually have scope over an entire phrase. All past-tense adverbials undergo some variation in intensity to describe its coverage over a phrase. Non-manual coverage of a clause is seen in yes-no questions and negation. In this case, the signal occurs during the entire clause. In particular, specific combinations of non-manual signals mark relative clauses.[Lid80] The following tables illustrate some non-manual signals which effect grammar or syntax.

LEXICAL NON-MANUAL SIGNALS

adverbial marker	cheek to shoulder
distant-future adverbial marker	puffed cheeks
adverb(1)	lips together and pushed outward without puckering, slight head tilt
adverb(2)	shoulder raised, head turned to side
adverb(3)	lips apart and pushed out, tongue protruding
assertion	slow head nod
imperative, SV or VS_{pro}	eye contact, frown.
negation	side-to-side head shake
pronomial reference	gaze in direction of spatial referent
rhetorical	brow squeezed, tilt head, slight pause
relative-clause marker	brow raise, backward head tilt, cheek and upper lip raised
tag-q	brow up, tilt head
topic marker O(t)SV	brow raise, slight backward, short pause
WH-question marker	brow squeezed, tilt head, hold sign
yes-no marker	brow raise, head and body forward

ARTICULATION OF LEXICAL TENSE MARKERS

PAST-TNS	bent b-CL tapping or moving toward shoulder
RECENT-PAST-TENSE(1)	restricted articulation of PAST-TENSE with co-occurrence of cheek-to-shoulder non-manual signal
RECENT-PAST-TENSE(2)	the sign RECENT with co-occurrence of cheek-to-shoulder non-manual signal
IMMEDIATE-PAST-TENSE	the sign NOW, however, closer to the body and co-occurrence of (teeth clenched, lips stretched, mouth corners pulled down) non-manual signal
FORMERLY-TENSE	5-CL moves in circular motion with thumb brushing against collar bone
#ex-TENSE	finger spelling of 'ex' articulated with sign; literal meaning "used to"

MODALS

CAN	two hands using s-CL, palm downward moving in a single downward restrained motion, generated at elbow.
MUST	single-handed, x-CL palm-forward, moving downward in restrained motion.
SHOULD	like MUST, but articulated with double movement
TEND-TO	single-handed open-8-CL, palm inward, moving outward and slightly upward from middle finger; contact with right chest; restrained movement has slight hold then quick acceleration; co-occurs with mouth gesture, heavily aspirated 'pah.'

2.2.5 Spatial Syntax

The grammar of a language provides a set of mechanisms that can be used to convey the semantic relations among lexical units required for the understanding of what is said. Because of ASL's unique language modality, which makes use of three-dimensional space, syntactic mechanisms are provided that are not available to spoken languages. Most signs are produced by executing the given specifications of each phenome category simultaneously. This is the three dimensional aspect of ASL. It uses spatial relationships to convey linguistic information. Spoken language vocalizations have no analogic relation to the distinctiveness of the person/object being referred to. In ASL, pointing is used for indexing and multidirectional verbs use motion to indicate their subject and objects. For example, the sign GIVE requires directional motion to establish who is the giver and the recipient. A variation on this idea, the sign for PITY, is directional only in it orientation. Space is also used to represent time (Fig. 2-9) and many signs express temporal relationships within the signing space by using direction to form symmetric sign-pairs. For example, YESTERDAY/TOMORROW are symmetric sign-pairs, where the motion of the former member is backward and the latter is forward. Otherwise, the signs are identical. (Fig. 2-10.) The following table summarizes the manual signals which effect syntax.

MANUAL SIGNALS

Handshapes	Locations	Movements
Orientation	Number of hands used	Segment duration
Repetition rate	Position of Stress	Internal features (i.e., hand-wiggling)

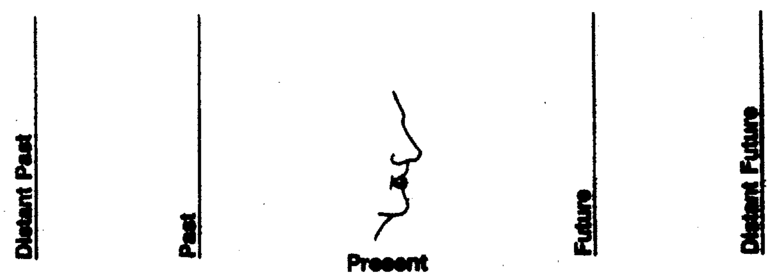


Figure 2-9: Spatial Representation of Time as a Lexical Item
Redrawn from [Rie78].

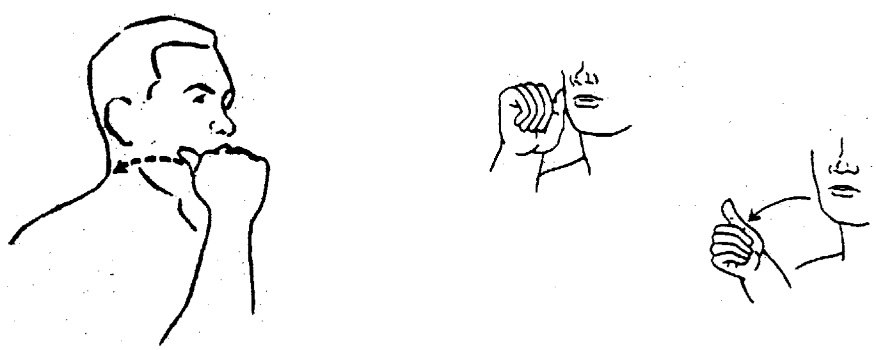


Figure 2-10: Signs for YESTERDAY and TOMORROW
Symmetric Sign-Pair: Identical sign with direction expressing temporal relation.
Redrawn from [Ste87].

Chapter 3

Constructing the Lexicon

To develop a more effective lexical structure for ASL, we need an adequate notational system for capturing the sign's spatial characteristics. Glossing, which involves an English representation of the sign, is commonly used but cannot show what the sign actually looks like. It is limited in its ability to convey much of the linguistic information inherent in a sign's structure. About a decade ago, Judy Shepard-Kegl devised a locative-based notational system for ASL that incorporates the aspectual and spatial qualities of the language. She surmised ASL as a language made in space with all lexical items ultimately built up from an inventory of shape and object classifiers plus five basic relational morphemes.[SK85] This chapter will introduce Kegl's notation and show how it has influenced the development of this project's lexicon. There is also a discussion of ASL signs, nouns, verbs, and pronouns, and what this notational system reveals about them. Then the ASL lexicon, as designed to exploit ASL's rich production qualities, is presented.

3.1 ASL Glossing

Glossing consists of uppercase English words which denote a sign. Unfortunately, glossing does not account for much of the inflectional information within the sign, such as subject and object agreement, aspect, etc. Kegl cites the sign for "ALREADY." The gloss of the sign is "FINISH," but it can also be translated as "already, or "have."[SK85] Much of the sign's morphology is also lost in the glossing notation. Another example is the one-handed version of the signs, "GIVE," "MOVE," and "INFORM." These signs are visually similar in ASL and while this relationship is not evident from their gloss notation, it can be seen with Kegl's notation. Also, glossing tells us nothing about how the signs are formed. For example, SUMMER starts at the chest, UGLY at the waist, and DRY at the forehead, each with a different palm orientation (*ori*). Only hand configuration and general pattern of movement are the same. (Fig. 3-1 to examples of other phonological parameters.) Glossing is enhanced with indexes and symbols to account for subject object agreement and aspect, however, there is still quite a bit of relevant sign information that is dropped.

3.2 Kegl Notational System

The sign morpheme unlike the spoken word is, for the most part, perceived simultaneously. Kegl uses an excellent analogy of a painting, which is composed of sequential brush strokes, but is perceived as a whole image. Therefore it makes sense to divide the sign aspectually rather than temporally. The entire lexicon and most of the grammar is locatively based, following the standard school of thought about the encoding of signs using *tab, dez, sig*, and *ori*. Therefore, it contains a great deal of morphological complexity of the sign. Here is a summary of Kegl's hypotheses regarding the aspectual characteristics of a sign.

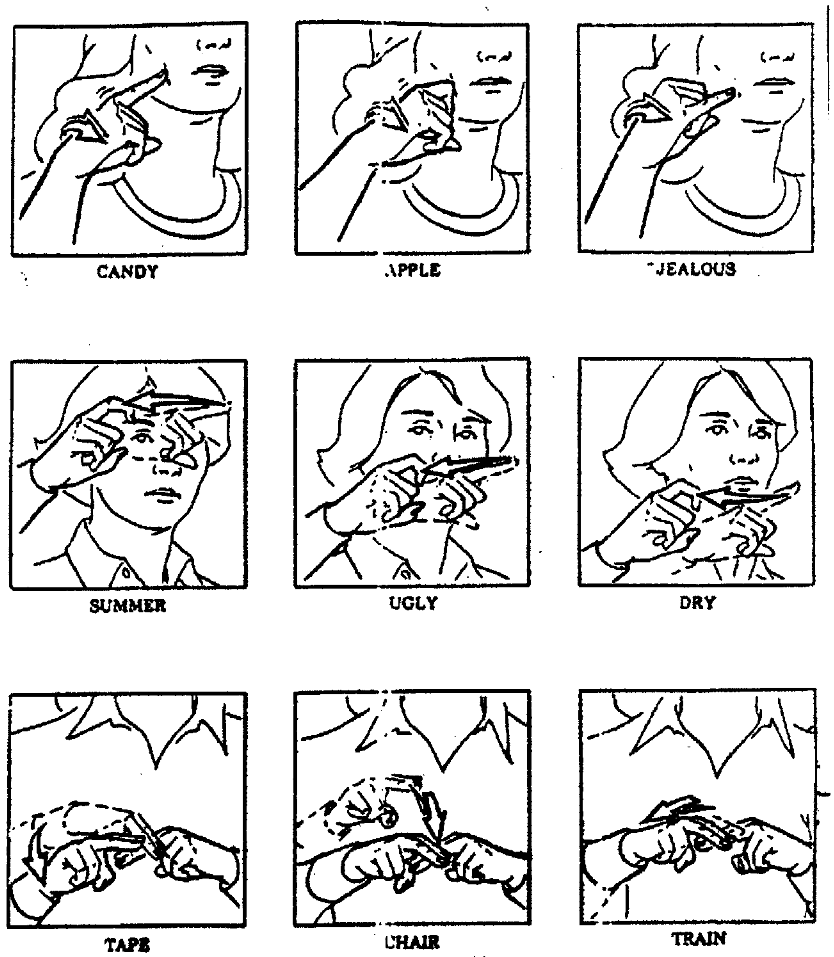


Figure 3-1: Phonological Components of ASL. Row 1: Sign changes only in *dez* (handshape). Row 2: Sign changes only in *tab* (location). Row 3: Sign changes only in *sig* (movement). *Redrawn from [Emm93].*

Locative Hypothesis

We assume that all signs are locatively based and can be encoded in terms of their location *(tab)*, shape *(dez)*, movement *(sig)*, and orientation *(ori)*.

Linear Precedence Hypothesis

ASL is morphologically complex and often sign-internal morphemes are sequenced. In other words, the articulation of the sign is temporally ordered. However, a sign is assumed to be entirely non-temporal. This is because the entire sign is seen as a whole (which is a function is its modality) and, therefore, the complete sign is thought to happen 'at once.' This hypothesis is furthered by noting that sign production involves an initial handshape that may disappear by the end of the sign.

Simultaneity Hypothesis

Two morphemes can be simultaneously produced and yet remain independent of (unordered with respect to) one another. Each morpheme may have a linear precedence within the sign, but are not ordered with respect to one another.

Partial Ordering Hypothesis

This is an extended case of the Simultaneity Hypothesis. It states that two elements can be unordered with respect to one another but both are ordered with respect to some third element.

Precedence/Dominance Hypothesis

This is a special case of the Simultaneity Hypothesis. It states that although unordered, there may still be a dominance relationship between two morphemes. In other words, even if they occur together, one could have scope over another (Fig. 3-2.)

3.2.1 Notations

Kegl uses a system consisting of five basic morphemes to describe a sign. There are initial and final locations, movement and termination of movement, all of which has domain over the Theme, which is typically a classifier handshape. All sign's are prefaced by the SBP (signer's body pronoun), which marks role prominence. (Fig. 3-3 is a representative Kegl word schema.)

KEGL NOTATIVE ELEMENTS

Signer's Body Pronoun	**SBP**	The signer's torso marks role prominence. When prominence is assigned to a person, during an event it means the event is seen from that person's perspective.
Terminators	**AT**	Indicates relation the role prominence marker holds with respect to a location. Occurs either at the beginning or end of a movement.
	ON	Specifies contact on a surface (or some thing).
	IN	Specifies containment (to be in some thing or bounded by some space).
	WARD	Orientation toward a goal or location.
Movements	**TO**	Movement to a location or goal.
	FROM	Movement away from a location or source.
Locative Argument Marker	**LOC**	Location in a space is reference point for movement or location; LOC may be indexed (i, j, ...n) to distinguish it from other LOCs in the signing space.
Theme	**THEME**	Classifier whose production corresponds to the production of the *Movement* part of sign and its *Terminator*.

3.2.2 ASL Word and Sign Structures

Words Types

Kegl notation handles various ASL word types, simple, complex, compound, phonological, and contractions. *Simple Words* contain a single movement (**TO** or **FROM**), single locative marker (**LOC**), single terminator (**IN**, **ON**, **AT**, **WARD**), and a single theme (**THEME**). *Complex Words* contain two movements, two terminators and a single theme. *Compounds* are combinations of words that behave as a single word. *Phonological words* consist of a word plus its clitics. Clitics are words that have not inherent stress and therefore must attach to an adjacent word. *Contractions* involve either a negative adjacent to a word or cliticization of pronominals.

Signs Types

Kegl also handles two major ASL sign types, simple and complex. *Simple Signs* have a minimal structure with *Movement* (**TO** or **FROM**) as the base of the sign, and either preceded or followed by the locative marker (**LOC**). **LOC** serves as a source (or goal) for the movement. The terminator is always between the *Movement* and **LOC**, whatever their respective order, followed by the **THEME**. Movement becomes the sign base and **LOC** either precedes or follows it. The **THEME** is a classifier (or word, i.e., J-o-h-n). Articulation of the classifier coincides with the articulation of the movement element and its terminator. The term indicates the spatial relation of the moving **THEME** at the end of its movement. The type of movement used is a function of its relative ordering and **LOC**. If **LOC** precedes *Movement*, **LOC** is the source and the movement is **FROM**. If **LOC** follows *Movement*, **LOC** is a goal and movement is **TO**. *Complex signs* have two *Movements* and one or two **LOCs** but only a single theme. The number of **LOCs** determine which of two complex word formats to use. Two **LOCs** mean the word is a source or goal word, whereas one **LOC** means the word is negated. In this instance, $\mathbf{LOC}_i$ serves as an affix that marks the nominals. A morphologically complex noun, like 'cup' (in ASL this is complex), has a structure which means literally “a rimmed curved object is on a flat surface” as in “the cup is on the table” (Fig. 3-5).

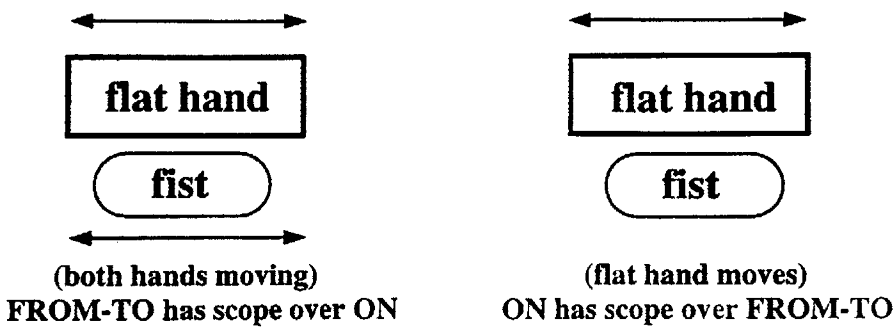


Figure 3-2: Precedence Dominance Hand Relationships
Redrawn from [SK85].

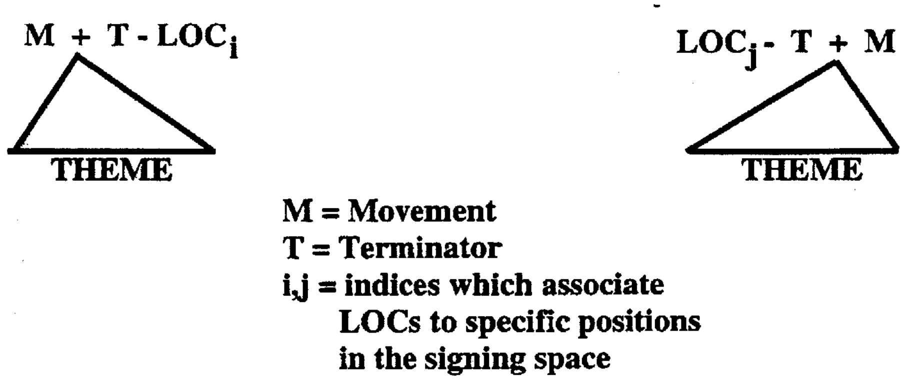


Figure 3-3: Schema Representations of ASL word for TO-type and FROM-type words.
Redrawn from [SK85].

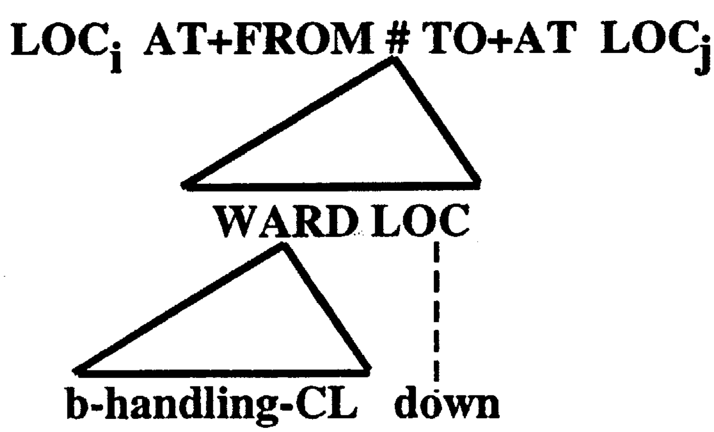


Figure 3-4: Generic Sign for Movement from i to j

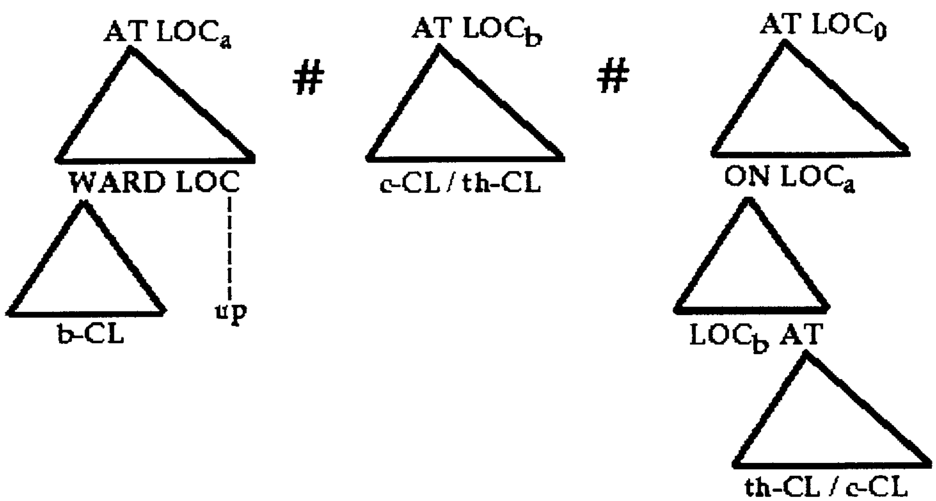


Figure 3-5: Complete Kegl Structure for CUP
Redrawn from [SK85].

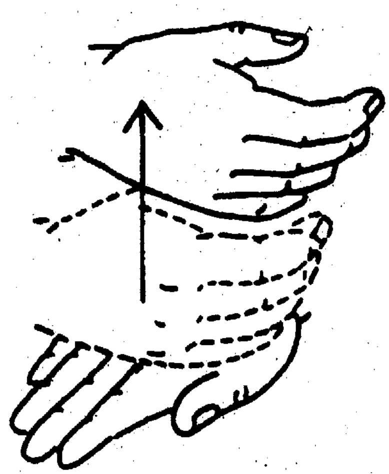


Figure 3-6: Sign for CUP
Redrawn from [Ste87].

Chapter 4

Method for ASL Lexicon Use In ASL to English Translation

4.1 Simplifying Assumptions

Assumption: Different lexical entries sharing the same sign have been omitted from this version of the ASL lexicon.

Assumption: Fingerspelling is not processed.

Assumption: Noun/verb pairs determined by reduplication are ignored.

Assumption: Single signs expressing a series of words are ignored.

4.2 Method

To be useful for interlingua translation, as much of the signer's linguistic intent as possible must be captured and appended to the output string. The challenge for the machine translation program is how to compensate for target language components that are not part of the ASL grammatical structure (and the reverse, as well). Because of ASL's unique properties, a direct mapping approach would lead to ambiguity, and in some cases, failure of the translation attempt. While there are several ways to approach this challenge, the best candidate would be a universal translator, which translates phrase *meaning* rather than attempting a direct mapping of syntactic constituents. The following schematic illustrates how an ASL-to-English translation system could be configured:

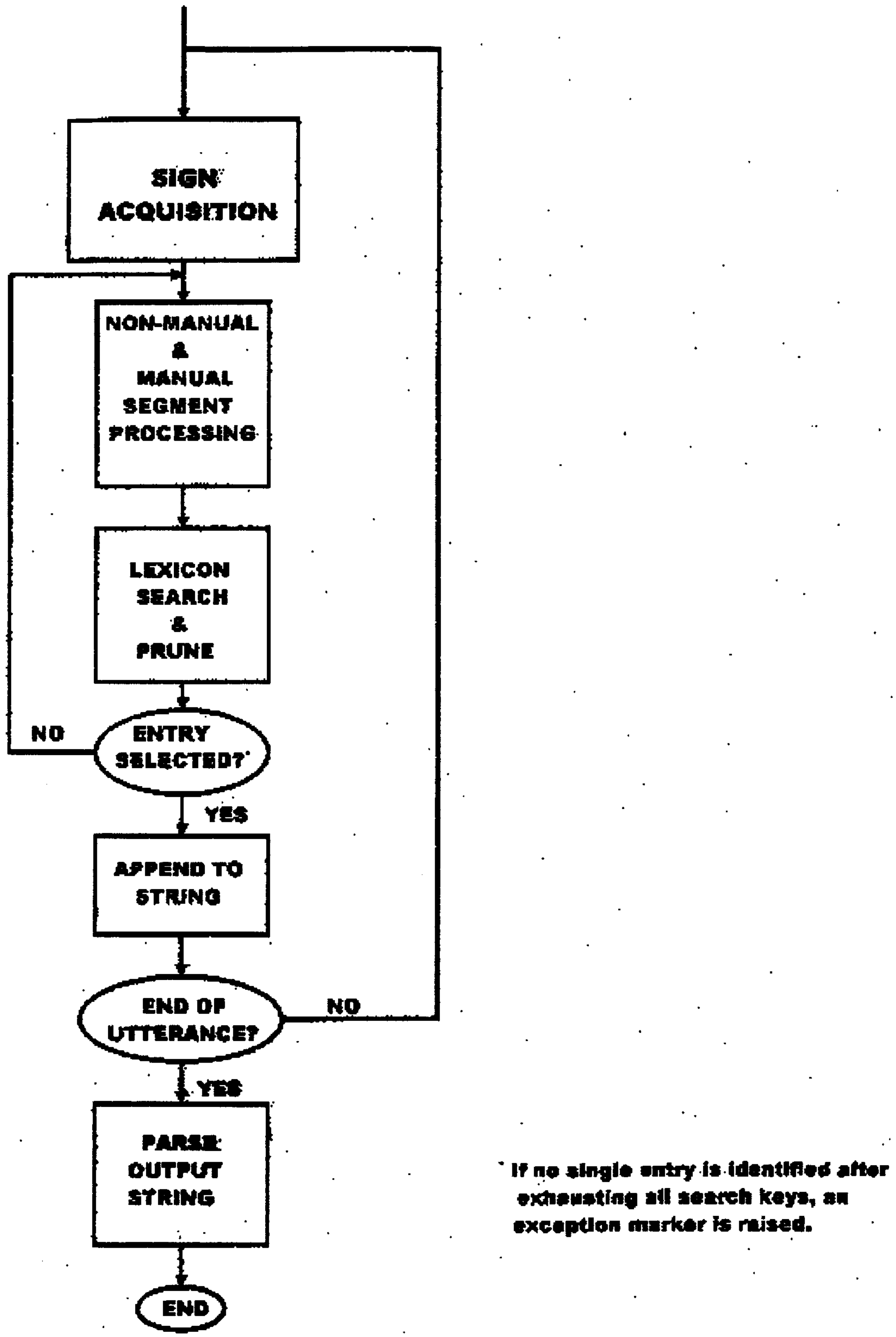


Figure 4-1: Schematic of ASL Translation System.

4.2.1 Sign Acquisition

A viable sign acquisition system would capture the manual and non-manual sign information. The data structure is designed to hold the sign morphemes features obtained from the camera's signal in preparation for lexical search. As the data structure is referenced, a corresponding lexicon entry is selected from the lexicon by comparing first the *sig* (movement) morpheme to those in the lexicon and pruning down the search space. Non-manual signals are used, if necessary, to resolve ambiguities between lexical candidates. Before the selected lexical entry is appended to the output string, any non-manual linguistic information is added. This type of lexical search speeds identification of an entry and removes the burden of sign identification from the imaging system.

Format

A lexicon entry is specifically structured to accommodate ASL features and contains information about the word, its category, and manual and non-manual features for the word's corresponding ASL sign. Some features have different default values for their category (i.e., verbs have the rest() feature set to (-), while nouns have this feature set to (+)).

Default Attributes and Values of Lexical Categories

```
ADJECTIVES
entry(word,adj
MF[sig(dom[],weak[]), tab(dom[],weak[]), dez(dom[],weak[]),
ori(dom[],weak[]), hands(number,sym(+/-)), freq(+/-), rest(+/-),
contact((+/-),(what,how),(where))],
NMF[eye(+/-), cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
mouth(+/-), head(+/-)]);
```

ADVERBS

```
entry(word,adv
MF[sig(dom[],weak[]), tab(dom[], weak[]), dez(dom[],weak[]),
ori(dom[],weak[]), hands(number,sym(+/-)), freq(+/-), rest(+/-),
contact((+/-),(what,how),(where))],
NMF[eye(+/-), cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
mouth(+/-), head(+/-)]);
```

AUXILLARIES

```
entry(word,aux,
MF[sig(dom[],weak[]), tab(dom[],weak[]), dez(dom[],weak[]),
ori(dom[],weak[]), hands(number,sym(+/-)), freq(+/-), rest(+/-),
contact((+/-),(what,how),(where))],
NMF[eye(+/-), cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
mouth(+/-), head(+/-)]);
```

NOUNS

```
entry(word,n,
MF[sig(dom[],weak[]), tab(dom[],weak[]), dez(dom[],weak[]),
ori(dom[],weak[]), hands(number,sym(+/-)), freq(+/-), rest(+),
contact((+/-),(what,how),(where))],
NMF[eye(+/-), cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
mouth(+/-), head(+/-)]);
```

PREPOSITIONS

```
entry(word,prep,
MF[sig(dom[],weak[]), tab(dom[],weak[]), dez(dom[],weak[]),
ori(dom[],weak[]),hands(number,sym(+/-)), freq(+/-), rest(+/-),
contact((+/-),(what,how),(where))],
NMF[eye(+/-), cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
```

```
mouth(+/-), head(+/-)]);
```

PRONOMINALS

```
entry(word,pro
MF[sig(dom[],weak[]), tab(dom[],weak[]),  dez(dom[],weak[]),
ori(dom[],weak[]),hands(number,sym(+/-)), freq(+/-), rest(+),
contact((+/-),(what,how),(where))],
NMF[eye(+/-),  cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
mouth(+/-), head(+/-)]);
```

VERBS

```
entry(word,v,
MF[sig(dom[],weak[]), tab(dom[],weak[]), dez(dom[],weak[]),
ori(dom[],weak[]),hands(number,sym(+/-)), freq(+/-), rest(-),
contact((+/-),(what,how),(where))],
NMF[eye(+/-), cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
mouth(+/-), head(+/-)]);
```

WH-NOUNS

```
entry(word,wh,
MF[sig(dom[],weak[]), tab(dom[],weak[]), dez(dom[],weak[]),
ori(dom[],weak[]), hands(number,sym(+/-)), freq(+/-), rest(+),
contact((+/-),(what,how),(where))],
NMF[eye(+/-), cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-),
mouth(+/-), head(+/-)]);
```

Lexicon Abbreviations

Attributes

word:	lexical item
c:	item category (noun, verb, pronoun, adverb, etc.)
MF:	manual feature list which contains *sig*, *tab*, *dez*, and *ori* information, number of hands involved and ±symmetry between hands, number of sign repetitions, and presence of movement restriction.
NMF:	non-manual feature list which contains information about eyes, brow, cheeks, head tilt, mouth, eyes, tongue, and nose configurations.

Sign Features - Manual

tab(dom[],weak[])	Sign location in relation to signer's body. Dom[] indicates dominate hand. Weak[] indicates non-dominate hand. Multiple instances of dom[] and weak[] are possible, in sign order, for complex signs. Possible values are: top, forehead, eyes, nose, ear, mouth, cheek, neck, chest, stomach, upper-arm, lower-arm, and hand.
sig(dom[],weak[])	Sign movement in relation to signer's body. Possible values are toward (body), forward, downward, upward, side (side-to-side), rotating, circular. No entry means the hands stay in same location.
dez(dom[],weak[])	Sign handshape. Possible values are classifier handshapes. See Appendix A for partial list of classifier handshapes.
ori(dom[],weak[])	Sign orientation indicates which part of hand is facing the floor. Possible values are palm (p), pinky (k), back of hand (b), and no orientation. No orientation indicates the hand is held vertical. In this case orientation is in relation the palm direction. Possible values are palm facing body (f), palm facing outward (o), palm facing leftward (l), and palm facing sides of body (s).
hands(num(1,2),sym($\pm$))	Number of hands used in sign and $\pm$hand symmetry.
freq($\pm$)	$\pm$Repetition of sign movement.
rest($\pm$)	$\pm$Restrictive sign movement. Nouns are classified as restrictive. Verbs are not.
contact(+/-,(what,how,where)	$\pm$Contact with other hand or body part. What is the hand initiating the contact, how contact made, and where the contact is made.

Sign Features - Non-manual

eye[]	Eye configuration Possible values are normal, wide, and slits. Note, there are many possible eye configurations, but we are starting with this small subset.
cheeks[]	Cheek configuration. Possible values are puffed, (sucked) in and normal .
brow[]	Brow configuration. Possible values are raised, furrow, and normal.
tongue($\pm$)	Tongue configuration. Possible values are regular (-) and stuck out (+).
nose[]	Nose configuration. Possible values are regular, twitch, and in.
mouth[]	Mouth configuration. Possible values are o-shape (o), closed (c), and curled upper lip (l). Note, there are many possible mouth configurations, but we are starting with this small subset.
head[]	Head tilt configuration. Possible values are up, down, left, right.

Example

Lexicon entry for the verb *eat*:

```
entry(eat,v, MF[sig(dom[toward],weak[]),
tab(dom[chin],weak[],dom[mouth],weak[]),
dez(dom[tips-CL],weak[]),  ori(dom[p],weak[]),hands(1,sym(-)),
freq(+),rest(-),contact(-)], NMF[eye(), cheeks(), brow(),tongue(),nose(),
mouth(),head()]);
```

No non-manual signals associated with identification of the sign *eat*, so the non-manual lexical attributes are not given values. Any non-manual signals extracted from the camera's signal represent linguistic information, such as lexical tense markers.

4.2.2 Lexicon Search

Entries are arranged in the lexicon by category and within category by word. The first ASL component searched is *movement*, the most determining sign feature. Some signs can be identified based on *movement* alone. Once a set of entries are selected based on *movement*, then *location* is checked. *Location*, rather than *handshape*, is the second search parameter because the *location* feature is easier to extract from the image and for some signs, this information, coupled with *movement*, will lead to a match. *Handshape* and *orientation* are more difficult features to extract from the image, therefore their processing done last. Other manual features, such as number of hands, hand symmetry, frequency of movement (repetition), and restriction of movement are retrieved and checked, as needed. Once a lexicon entry is identified, any remaining processing is halted. The entry, along with linguistic non-manual information, is appended to an output file for later parsing. Rather than relying solely on the visual system for sign identification, sign segments are extracted and values are stored in the appropriate data structures. The algorithm then uses results from the previous passes to process subsequent segment information. In instances of ambiguity, additional lexical information (freq(), rest(), touch(), hands(), etc.) is used to extract a single candidate. Once the sign has been matched with an entry in the lexicon, the entry and its non-manual lexical markers are appended to the output string. This lookup and append process continues until the individual stops signing.

Data Structure

The following data structure is loaded with the morpheme segment information gathered from the camera signal.

```
typedef struct {
    char *sig[15];
    char *tab[10];
    char *dez[10];
    char *ori;
    char *hands[20];
    boolean freq;
    boolean rest;
    char *who[10];
    char *how[10]
    char *where[10]
} manual;

typedef struct {
    char *eye[6];
    char *cheeks[6];
    char *brow[6];
```

```
    boolean tongue;
    char *nose[7];
    char *mouth[8];
    char *head[5];
} nonmanual;

typedef struct {
    manual;
    nonmanual;
} image;
```

Algorithm

Non-Manual Signal Processing

The image is sampled. The non-manual signal are recorded and appended to the output string. If no other non-manual signals are detected, process manual signals.

Manual Signal Processing

As mentioned earlier, extract and analyze each morpheme segment (in this case *sig, tab, dez, ori*, or some other manual feature) and assign a value that falls within the probabilistic threshold value for that signal. Perform lexical search and prune until a single candidate is selected or an exception marker returned. Append selection to output string. An exception marker indicates no entry was found or unresolved ambiguity exists between several candidates.

Perform lexicon search.

The search key value is compared to the lexicon and matching entries are extracted. The search key is updated to the next significant morpheme value in the data structure and the current set of selected entries is search.

4.2.3 Phrase Parsing

Once "eou" is detected, the parse routine is activated. The output string is parsed into its linguistic constituents using the Earley parsing algorithm. Once parsed, this string can be used as input to a properly configured universal translator program.

ASL Phrase Structure Rules

```
((ROOT ==> S)
(ROOT ==> Q)
(S ==> NP VP)
(S ==> N TIME-ADV VP) ; Sentences with Time Adverbials
(S ==> TIME-ADV NV)
(S ==> NP VP TIME-ADV)
(S ==> LTM NV)    ; Sentences w/Lexical Tense Markers
(S ==> NV LTM)
(S ==> LTM S/NEG)
(S ==> N LTM VP)
(S ==> LTM ASP)
(S ==> NP MODAL VP)    ; Sentences with Modal
(S ==> MODAL N V N)
(S ==> NP ASPECT VP)  ; Sentences with Aspect
(S ==> S/NEG)
(S ==> S/TOPIC)
(S ==> S/WH)
(S ==> S/AFFIRM)
(S ==> NP ASPECT VP)
(S ==>)                ; S->epsilon
(Q ==> WH NV)
(Q ==> WH NV WH)
(Q ==> NV2 WH V N WH)
(Q ==> NV2 WH V ADV WH)
(Q ==> YN V NV)
(S/NEG ==> NEG NV)     ; Sentences with negative
(S/NEG ==> NEG ASPECT NV)
(S/NEG ==> MODAL NEG NV)
```

```
    (S/NEG ==> NV NEG NV)
    (S/NEG ==> N LTM NEG NV)
    (S/NEG ==> LTM N NEG NV)
    (S/NEG ==> LTM NV4)
    (S/NEG ==> N NEG NV LTM)
    (S/NEG ==> N NEG NV)
    (S/NEG ==> N NEG ADV NV)
    (S/TOPIC ==> TOPIC N PRO VP) ; Sentences with topic
    (S/TOPIC ==> TOPIC N V AFFIRM NP)
    (S/TOPIC ==> TOPIC N TOPIC N VP)
    (S/AFFIRM ==> NP V AFFIRM N) ; Sentences w/affirmation
    (S/AFFIRM ==> N LTM VP AFFIRM LTM N)
    (S/WH ==> NV WHM NVN)        ; wh-sentences
    (S/WH ==> NV WHM V N ADV)
    (VP ==> N VP LTM)
    (VP ==> ADV V)
    (VP ==> V)
    (VP ==> V NP)
    (VP ==> V ADV)
    (VP ==> N VP)
    (PP ==> P NP)
    (NP ==> N)
    (NP ==> PRO)
    (NV ==> NP VP)
    (NV2 ==> N V N)
    (N3V ==> NEG ADV VP)
    (NV4 ==>  NEG PRO ADV VP)

))
```

```
;==========
; TERMINALS
;==========
;----------------------
; Adjectives
;----------------------
                  (black ADJ)
                  (dry ADJ)
                  (enthusiastic ADJ)
                  (jealous ADJ)
                  (red ADJ)
                  (ugly ADJ)
;----------------------
; Pronouns
;----------------------
                  (I PRO)
                  (xi1 PRO)
                  (xi2 PRO)
                  (xi3 PRO)
                  (you PRO)
                  (he PRO)
                  (she PRO)
                  (they PRO)
                  (we PRO)
;----------------------
; Nouns
;----------------------
  (John N)
                  (Mary N)
                  (airplane N)
```

```
                  (apple N)
                  (book N)
                  (buy N)
                  (can N)
                  (candy N)
                  (cat N)
                  (chair N)
                  (chocolate N)
                  (corn N)
                  (cup N)
                  (elephant N)
                  (eyes N)
                  (fish N)
                  (flower N)
                  (floor N)
                  (hammer N)
                  (head N)
                  (house N)
                  (knife N)
                  (love N)
                  (skill N)
                  (summer N)
                  (table N)
                  (tape N)
                  (tomorrow N)
                  (yesterday N)
;----------------------
; Adverbs
;----------------------
                  (entry ADV)
```

```
                (tomorrow ADV)
                (yesterday ADV)
                (what ADV)
;----------------------
; Verbs
;----------------------
                (buy V)
                (eat V)
                (fall V)
                (fish V)
                (fly V)
                (give V)
                (hammer V)
                (inform V)
                (like V)
                (love V)
                (move V)
                (see V)
                (sit V)
                (want V)
                (wonder V)
;----------------------
; Misc
;----------------------
                (not adv)
                (who WH)
                (what WH)
                (whom WH)
                (yes-no? YN)
                (topic-marker TOPIC)
```

```
                    (head-nod AFFIRM)
                    (finish-perfect-asp ASPECT)
                    (wh-marker WHM)
;----------------------
; Lexical Tense Markers
;----------------------
                    (past-tense LTM)
                    (distant-future-tense LTM)
                    (recent-past-tense LTM)
                    (future-tense LTM)
                    (recent LTM)
                    (immediate-past-tense LTM)
                    (formerly-tense LTM)
                    (ex-tense LTM)
                    (up-to-now-tense LTM)
;----------------------
; Modals
;----------------------
                    (can-modal MODAL)
                    (must-modal MODAL)
                    (should-modal MODAL)
                    (tend-to-modal MODAL)
;----------------------
; Time Adverbials
;----------------------
                    (distant-future-adv TIME-ADV)
                    (past-adv TIME-ADV)
                    (recent-past-adv TIME-ADV)
                    (future-adv TIME-ADV)
                    (recentadv TIME-ADV)
```

```
                (immediate-past-adv TIME-ADV)
                (formerly-adv TIME-ADV)
                (ex-adv TIME-ADV)
                (up-to-now-adv TIME-ADV)
))
```

4.2.4 Output

With the linguistic constituents assigned and the ASL phrase parsed, we are ready for input into a properly configured universal translation program. One such universal translator program, Unitrans, would require the setup of ASL-specific grammar information. An ASL-configured Unitrans program could translate ASL to English, Spanish, Dutch, or German. Program output can then be directed to a speech processing program, such as SpeakEasy, for output to audio speakers. This entire process will enable the ASL signer to have their utterance captured and transformed so the ASL-illiterate user can understand it.

Chapter 5

Conclusion

5.1 Discussion

Our lexicon structure is designed to handle ASL-specific linguistic components and exploit them for sign identification. This method allows for system robustness because entry identification is derived from its significant morphemes. Variances in sign formation will be more easily filtered out, since it is the individual morphemes of the sign that are identified. Non-manual signals are used to add linguistic information to the output string and in some cases resolve ambiguities. Second, the morpheme value assignments and search processes remove the bulk of the responsibility for sign recognition from the visual system by only requiring it to identify individual morphemes, as opposed to the entire sign. Discrimination of a particular movement involves less processing than the identification of the entire sign. Third, in actual use this method of searching the lexicon may speed up the retrieval process because once a particular morpheme search selects a group of candidates, the search continues with only those candidates. If more information is needed, then the next image segment is extracted from the image, its morpheme is assigned a value and becomes the search key. Also, search is halted once a single entry is selected. In many instances the sign can be identified from only a portion of the image.

5.2 Other Research in This Area

There are several methods being studied for sign language acquisition. They range from tethered-glove devices to light-point systems. The former is being developed at MIT and several other laboratories with hopes of becoming an independent sign acquisition tool for use in practical applications. The latter, light-point, is being used as an ASL research tool, and is not currently being looked at for use in assistive technologies.

5.3 Looking Ahead

Sign acquisition is a very challenging slice of the ASL-to-English translation pie, for it will determine how reliable, and consequently how useful, the acquired sign information will be. Use in everyday environments, such as home, office, and public areas, introduces all kinds of problems, such as signal noise and variance in lighting and background, that will have to be addressed. Also, further development of the lexicon schema introduced in this text, including processing of ASL language variance is needed. While projects are underway elsewhere, there is still a need for more study of ASL translation and its application to assistive technologies. Assistive technologies for the Deaf bring with it issues of portability, usability, and versatility of this technology. An ASL-to-English translator would be invaluable in the workplace, schools, and for use in emergency situations. These more essential uses are driving the development of this technology. The ASL lexicon structure presented here, which incorporates the idea of identifying image segments to ease the processing burden on the vision system while providing for more robust processing of non-manual signals, is a step toward a useful translator. A secondary application for this technology is interactive ASL computer tutorial programs that engage the user in signed conversation.

Appendix A

Sign Language References

A.1 Alphabet

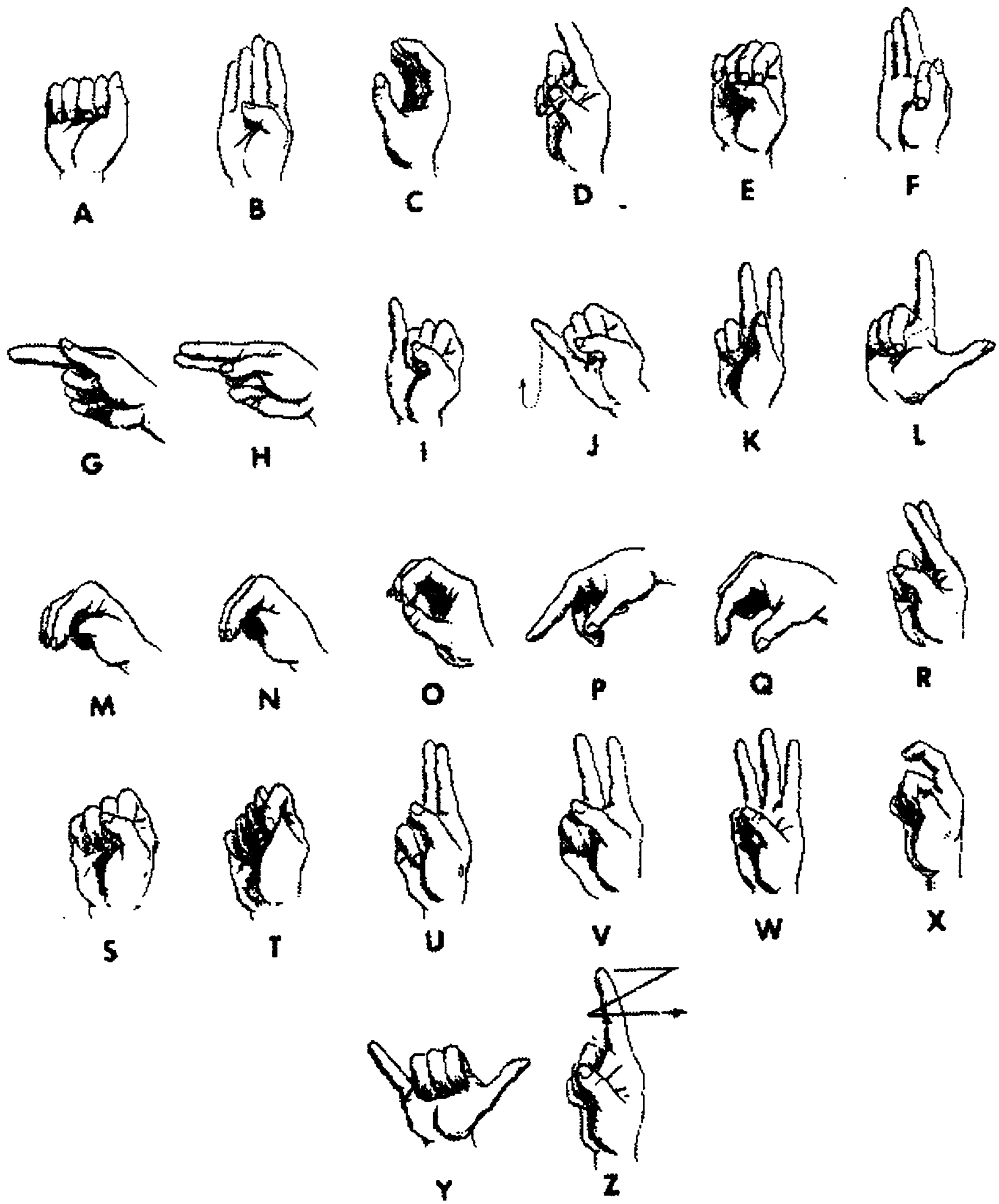


Figure A-1: American Sign Language Alphabet
Redrawn from [Ste87].

A.2 Classifier Handshapes

Some ASL Classifier Handshapes

4-CL	four with fingers separated; represents thin objects.
5-CL	fingers spread apart with hands and fingers cupped; combination of 4-CL and c-CL.
a-CL	represents stationary objects.
b-CL	flat open hand with fingers together; represents a flat surface or object.
claw-CL	claw hand shake; combination of curved-4-CL and c-CL.
curved-b-CL	curved-b-CL.
c-CL	cupped hand; represents curved surface or rimmed object.
g-CL	index finger; represents a long, thin object, small amount, or small width.
g-handling-CL	move index finger back and forth.
h-CL	index and middle finger adjacent; represents narrow objects.
i-CL	pinky little finger extended from fist; represents very thin objects.
L-CL	represents rectangular shapes.
curved-L-CL	indicates thickness.
o-CL	represents cylindrical objects.
open-o-CL	o-handshape, with middle, ring, and pinky fingers spread and extended.

open-8-CL	middle finger perpendicular to palm, other fingers on plane with the palm.
s-CL	fist. represents solid, round objects.
thumb-CL	represents object that is taller than wide. also represents copy of whatever hand shape it is opposed to.
tips-CL	tips of all fingers and thumb meets at each point.
v-CL	two separated parallel straight objects; usually represents person, object or animal having legs.

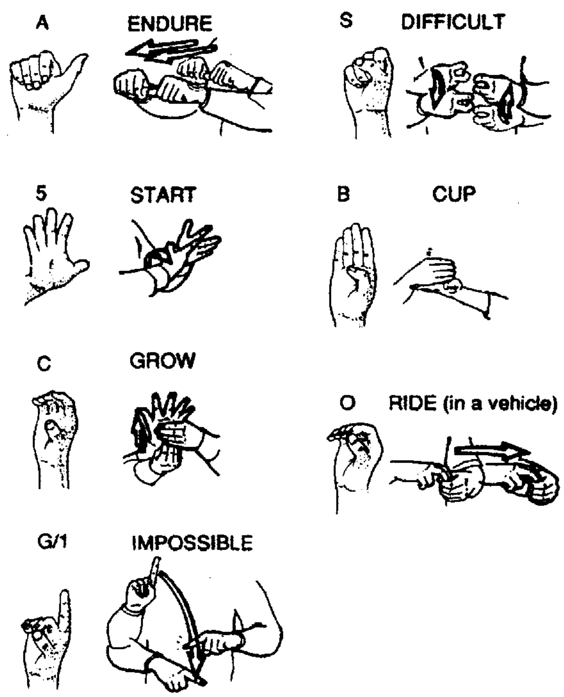


Figure A-2: Use of Classifier Handshapes in Sign Formation
Redrawn from [Ble93].

A.3 ASL Vocabulary and Lexicon

Adjectives

```
entry(black, adj,
MF[sig(dom[left-to-right],weak[]), tab(dom[eyebrow],weak[]),
dez(dom[g-CL],weak[]), ori(dom[p],weak[]), hands(1,sym(-)),
freq(-),rest(+), contact(+,dom[tips,on],eyebrow)], NMF[eye(+/-),
cheeks(+/-), brow(+/-), tongue(+/-), nose(+/-), mouth(+/-),
head(+/-)]);

entry(dry,adj,
MF[sig(dom[left-to-right],weak[]), tab(dom[chin],weak[]),
dez(dom[curved-g-CL],weak[]), ori(dom[p],weak[]),
hands(1,sym(-)),freq(-),rest(+)], NMF[eye(), cheeks(), brow(),
tongue(),nose(), mouth(), head()]);

entry(enthusiastic,adj,
MF[sig(dom[forward],weak[backward]), tab(dom[chest],weak[chest]),
dez(dom[b-thumb-CL],weak[b-thumb-CL]), ori(dom[k],weak[k]),
hands(2,sym(+)), freq(+),rest(+),
contact(+,dom[palm,against],weak[palm])], NMF[eye(+/-), cheeks(+/-),
brow(+/-), tongue(+/-),nose(+/-), mouth(+/-), head(+/-)]);

entry(jealous,adj,
MF[sig(dom[small-arc-forward],weak[]), tab(dom[cheek],weak[]),
dez(dom[j-CL],weak[]), ori(dom[p],weak[]),
hands(1,sym(-)),freq(-),rest(+),
contact(+,dom[finger-tip,on],cheek)], NMF[eye(), cheeks(), brow(),
```

```
tongue(),nose(), mouth(), head()]);

entry(red,adj,
MF[sig(dom[up-down],weak[]), tab(dom[lips],weak[]),
dez(dom[g-CL],weak[]), ori(dom[f],weak[]), hands(1,sym(-)), freq(+),
rest(+), contact(+,dom[tips,on],lips)], NMF[eye(+/-), cheeks(+/-),
brow(+/-), tongue(+/-), nose(+/-), mouth(+/-), head(+/-)]);

entry(ugly,adj,
MF[sig(dom[left-to-right],weak[]), tab(dom[nose],weak[]),
dez(dom[curved-g-CL],weak[]), ori(dom[p],weak[]), hands(1,sym(-)),
freq(-), rest(+)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);
```

Pronouns

```
entry(he,pro,
MF[sig([],weak[],dom[forward],weak[]),
tab(dom[forehead],weak[],dom[chest],weak[]),
dez(dom[flat-tips-CL],weak[],dom[g-CL],weak[]),
ori(dom[p],weak[],dom[k],weak[]), hands(1,sym(-)), freq(-), rest(-),
contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(),
head()]);

entry(I,pro,
MF[sig(dom[],weak[]), tab(dom[chest],weak[]), dez(dom[i-CL],weak[]),
ori(dom[l],weak[]), hands(1,sym(-)), freq(-), rest(+),
contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(),
head()]);
```

```
entry(I,pro,
MF[sig(dom[toward],weak[]), tab(dom[chest],weak[]), dez(dom[g-CL],weak[]),
ori(dom[k],weak[]), hands(1,sym(-)), freq(-), rest(+), contact(-)],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(she,pro,
MF[sig(dom[downward],weak[],
tab(dom[cheek],weak[]), tab(dom[cheek],weak[],dom[chest],weak[]),
dez(dom[a-CL],weak[],dom[g-CL],weak[]), ori(dom[s],weak[],dom[k],weak[]),
hands(1,sym(-)), freq(-), rest(-), contact(+,dom[thumb,on],hand)],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(they,pro,
MF[sig(dom[left-to-right],weak[]), tab(dom[left],weak[]),
dez(dom[g-CL],weak[]), ori(dom[o],weak[]), hands(1,sym(-)), freq(+),
rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);

entry(we,pro,
MF[sig(dom[circular-left],weak[]),
tab(dom[right-shoulder],weak[],dom[left-shoulder],weak[]),
dez(dom[g-CL],weak[]), ori(dom[f],weak[]), hands(1,sym(-)), freq(-),
rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);

entry(we,pro,
MF[sig(dom[circular-left],weak[]),
tab(dom[right-shoulder],weak[],dom[left-shoulder],weak[]),
dez(dom[w-CL],weak[]), ori(dom[o],weak[]), hands(1,sym(-)), freq(-),
rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
```

```
mouth(), head()]);

entry(you,pro,
MF[sig(dom[arc],weak[]), tab(dom[left],weak[],dom[right],weak[]),
dez(dom[g-CL],weak[]), ori(dom[k],weak[],dom[p],weak[]),
hands(1,sym(-)), freq(-), rest(-), contact(-)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(you,pro,
MF[sig(dom[forward],weak[]), tab(dom[chest],weak[]),
dez(dom[g-CL],weak[]), ori(dom[k],weak[],dom[p],weak[]),
hands(1,sym(-)), freq(-), rest(-), contact(-)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(xi2,pro,
MF[sig(dom[forward],weak[]), tab(dom[chest],weak[]),
dez(dom[g-CL],weak[]), ori(dom[k],weak[],dom[p],weak[]),
hands(1,sym(-)), freq(-), rest(-), contact(-)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(xi3,pro,
MF[sig(dom[angle-left],weak[]), tab(dom[chest],weak[]),
dez(dom[g-CL],weak[]), ori(dom[k],weak[],dom[p],weak[]),
hands(1,sym(-)), freq(-), rest(-), contact(-)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(xi3,pro,
MF[sig(dom[angle-right],weak[]), tab(dom[chest],weak[]),
dez(dom[g-CL],weak[]), ori(dom[k],weak[],dom[p],weak[]),
hands(1,sym(-)), freq(-), rest(-), contact(-)], NMF[eye(), cheeks(),
```

```
brow(), tongue(), nose(), mouth(), head()]);
```

Nouns

```
entry(airplane,n,
MF[sig(dom[forward],weak[],dom[backward],weak[]),
tab(dom[shoulder],weak[]), dez(dom[y-index-CL],weak[]),
ori(dom[p],weak[]), hands(1,sym(-)), freq(-), rest(+), contact(-),
contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);

entry(apple,n,
MF[sig(dom[small-arc-forward],weak[]), tab(dom[cheek],weak[]),
dez(dom[g-CL],weak[]), ori(dom[p],weak[]), hands(1,sym(-)), freq(-),
rest(+), contact(-), contact(+,dom[finger-tip,on],cheek)], NMF[eye(),
cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(book,n,
MF[sig(dom[],weak[]), tab(dom[chest],weak[chest]),
dez(dom[s-index-CL],weak[b-CL]), ori(dom[k],weak[k],dom[b],weak[b]),
hands(2,sym(+)), freq(-), rest(+), contact(-)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(buy,n,
MF[sig(dom[],weak[],dom[small-arc-forward],weak[]),
tab(dom[chest],weak[chest]), dez(dom[c-CL],weak[b-CL]),
ori(dom[b],weak[b]), hands(2,sym(-)), freq(-), rest(+), contact(-),
contact(+,dom[hand,atop],weak[palm])], NMF[eye(), cheeks(), brow(),
tongue(), nose(), mouth(), head()]);
```

```
entry(can,n,
MF[sig(dom[downward],weak[downward]), tab(dom[chest],weak[chest]),
dez(dom[a-CL],weak[a-CL]), ori(dom[p],weak[p]), hands(2,sym(+)),
freq(-), rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(candy,n,
MF[sig(dom[small-arc-forward],weak[]), tab(dom[cheek],weak[]),
dez(dom[g-CL],weak[]), ori(dom[p],weak[]), hands(1,sym(-)), freq(-),
rest(+), contact(+,dom[finger-tip,on],cheek)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(cat,n,
MF[sig(dom[right],weak[left],dom[back-and-forth],weak[]),
tab(dom[upper-lip],weak[upper-lip],dom[chest],weak[chest]),
dez(dom[open-o-CL],weak[open-o-CL],dom[c-CL],weak[c-CL]),
ori(dom[s],weak[s],dom[p],weak[p]), hands(2,sym(-)), freq(-), rest(+),
contact(+,dom[],weak[],dom[fingers,atop],weak[hand])], NMF[eye(),
cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(chair,n,
MF[sig(dom[downward],weak[],dom[downward],weak[downward]),
tab(dom[chest],weak[waist]), dez(dom[h-CL],weak[h-CL]),
ori(dom[p],weak[p]), hands(2,sym(+)), freq(-), rest(+),
contact(+,dom[],weak[],dom[fingers,atop],weak[fingers])], NMF[eye(),
cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(chocolate,n,
MF[sig(dom[],weak[]), tab(dom[chest],weak[chest]),
```

```
dez(dom[c-CL],weak[s-CL]), ori(dom[o],weak[p]), hands(2,sym(-)),
freq(-), rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(corn,n,
MF[sig(dom[],weak[]), tab(dom[waist],weak[waist]), dez(dom[],weak[]),
ori(dom[k],weak[k]), hands(2,sym(-)), freq(+), rest(+), contact(-)],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(cup,n,
MF[sig(dom[],weak[],dom[upward],weak[]), tab(dom[waist],weak[waist]),
dez(dom[c-CL],weak[b-CL]), ori(dom[k],weak[b],dom[],weak[]),
hands(2,sym(-)), freq(-), rest(+),
contact(+,dom[c-CL,atop],weak[palm],dom[],weak[])], NMF[eye(),
cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(elephant,n,
MF[sig(dom[circular-forward],weak[]),
tab(dom[nose],weak[],dom[chest],weak[]), dez(dom[curved-b-CL],weak[]),
ori(dom[o],weak[],dom[f],weak[]), hands(1,sym(-)), freq(-), rest(+),
contact(+,dom[hand-back],against,nose)],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(eyes,n,
MF[sig(dom[],weak[]), tab(dom[eye],weak[]), dez(dom[g-CL],weak[]),
ori(dom[f],weak[]), hands(1,sym(-)), freq(-), rest(+),
contact(+,dom[finger,against],eye)], NMF[eye(), cheeks(), brow(),
tongue(), nose(), mouth(), head()]);

entry(eyes,n,
```

```
MF[sig(dom[],weak[],dom[left],weak[]), tab(dom[eye],weak[]),
dez(dom[g-CL],weak[]), ori(dom[f],weak[]), hands(1,sym(-)), freq(-),
rest(+), contact(+,dom[finger,against],eye)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(fish,n,
MF[sig(dom[left-to-right],weak[],(dom[forward],weak[]),
tab(dom[waist],weak[]), dez(dom[h-CL],weak[]), ori(dom[k],weak[]),
hands(1,sym(-)), contact(), freq(+), rest(+), contact(-)], NMF[eye(),
cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(fish,n,
MF[sig(dom[left-to-right],weak[],(dom[forward],weak[forward]),
tab(dom[waist],weak[waist]), dez(dom[h-CL],weak[h-CL]),
ori(dom[k],weak[k]), hands(2,sym(+)),
contact(dom[],weak[tips,dom(palm-base)]), freq(+), rest(+), contact(-)],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(flower,n,
MF[sig(dom[left],weak[]),
tab(dom[right-nostril],weak[],dom[left-nostril],weak[]),
dez(dom[tips-CL],weak[]), ori(dom[f],weak[]), hands(1,sym(-)), freq(-),
rest(+), contact(+,dom[tips,against],nostrils)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(hammer,n,
MF[sig(dom[down-to-up],weak[]), tab(dom[waist],weak[]),
dez(dom[a-CL],weak[]), ori(dom[k],weak[]), hands(1,sym(-)), freq(+),
rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);
```

```
entry(head,n,
MF[sig(dom[downward],weak[]), tab(dom[forehead],weak[],dom[jaw],weak[]),
dez(dom[right-angle-CL],weak[]), ori(dom[s],weak[s]), hands(1,sym(-)),
freq(-), rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(house,n,
MF[sig(dom[down-right],weak[down-left],dom[down],weak[down]),
tab(dom[forhead],weak[forhead],dom[shoulder],weak[shoulder]),
dez(dom[b-CL],weak[b-CL]), ori(dom[p],weak[p],dom[l],weak[l]),
hands(2,sym(+)), freq(+), rest(+), contact(-)],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(knife,n,
MF[sig(dom[forward],weak[]), tab(dom[chest],weak[chest]),
dez(dom[g-CL],weak[g-CL]), ori(dom[k],weak[k]), hands(2,sym(-)),
freq(-), rest(+), contact(+,dom[finger,atop],weak[finger])],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(love,n,
MF[sig(dom[],weak[]), tab(dom[chest],weak[chest]),
dez(dom[5-CL],weak[5-CL],dom[5-CL]), ori(dom[p],weak[p]),
hands(2,sym(+)), freq(-), rest(-), contact(+,dom[wrist,atop],weak[wrist])],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(love,n,
MF[sig(dom[],weak[]), tab(dom[chest],weak[chest]),
dez(dom[5-CL],weak[s-CL],dom[s-CL]), ori(dom[p],weak[p]), hands(2,sym(+)),
freq(-), rest(-), contact(+,dom[palm,atop],weak[hand])], NMF[eye(),
```

```
cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(skill,n,
MF[sig(dom[down-arc],weak[]), tab(dom[chest],weak[chest]),
dez(dom[c-CL],weak[b-CL]), ori(dom[b],weak[k],dom[k],weak[k]),
hands(2,sym(-)), freq(-), rest(+),
contact(+,dom[palm,underneath],weak[pinky])], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(summer,n,
MF[sig(dom[left-to-right],weak[]), tab(dom[forehead],weak[]),
dez(dom[curved-g-CL],weak[]), ori(dom[p],weak[]), hands(1,sym(-)),
freq(-), rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(table,n,
MF[sig(dom[right],weak[left],dom[down],weak[down]),
tab(dom[chest],weak[chest],dom[waist],weak[waist]),
dez(dom[b-CL],weak[b-CL],dom[p-CL],weak[p-CL]),
ori(dom[p],weak[p]), hands(2,sym(+)), freq(-), rest(+), contact(-)],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(tape,n,
MF[sig(dom[small-arc],weak[],dom[downward],weak[downward]),
tab(dom[chest],weak[waist]), dez(dom[h-CL],weak[h-CL]),
ori(dom[p],weak[p]), hands(2,sym(+)), freq(-), rest(+),
contact(+,dom[fingers,atop],weak[fingers])], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(train,n,
```

```
MF[sig(dom[rightward],weak[],dom[downward],weak[downward]),
tab(dom[chest],weak[waist]), dez(dom[h-CL],weak[h-CL]),
ori(dom[p],weak[p]), hands(2,sym(+)), freq(-), rest(+),
contact(+,dom[fingers,atop],weak[fingers])], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(tomorrow,n,
MF[sig(dom[backward],weak[]), tab(dom[cheek],weak[]),
dez(dom[a-CL],weak[]), ori(dom[s],weak[]), hands(1,sym(-)), freq(-),
rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);
```

Wh-nouns

```
entry(what,wh
MF[sig(dom[left-to-right],weak[]), tab(dom[chest],weak[chest]),
dez(dom[g-CL],weak[5-hand-CL]), ori(dom[k],weak[b]), hands(2,sym(-)),
freq(-), rest(+), contact(+,dom[fingers,along],weak[fingers]),
NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);

entry(what,pro,
MF[sig(dom[left-to-right],weak[]), tab(dom[lips],weak[]),
dez(dom[g-CL],weak[]), ori(dom[f],weak[]), hands(1,sym(-)), freq(+),
rest(+), contact(-), NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(pursed), head()]);
```

Adverbs

```
entry(always,adv,
MF[sig(dom[circular-left],weak[]), tab(dom[front-chest],weak[]),
dez(dom[g-CL],weak[]), ori(dom[k],weak[]), hands(1,sym(-)), freq(-),
rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(not,adv,
MF(sig(dom[],weak[],dom[right],weak[left]), tab(dom[chest],weak[chest]),
dez(dom[b-CL],weak[b-CL]), ori(dom[p],weak[p]), hands(2,sym(+)), freq(-),
rest(+), contact(+, dom[wrist,atop],weak[wrist])], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()];

entry(not,adv,
MF(sig(dom[forward],weak[]), tab(dom[chin]),
dez(dom[a-CL]), ori(dom[l]), hands(1,sym(-)), freq(-),
rest(+), contact(+, dom[thumb,against],chin)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()];

entry(tomorrow,adv,
MF[sig(dom[arc],weak[]), tab(dom[shoulder],weak[],dom[chest],weak[]),
dez(dom[a-CL],weak[]), ori(dom[s],weak[k]), hands(1,sym(-)), freq(-),
rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);
```

Verbs

```
entry(buy,v,
MF[sig(dom[],weak[],dom[forward],weak[]),
tab(dom[waist],weak[waist],dom[chest],weak[waist]),
dez(dom[c-CL],weak[b-CL]), ori(dom[b],weak[b]), hands(2,sym(-)), freq(-),
```

```
rest(-), contact(+,dom[hand,atop],weak[palm])], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(eat,v,
MF[sig(dom[toward],weak[]), tab(dom[chin],weak[],dom[mouth],weak[]),
dez(dom[tips-CL],weak[]), ori(dom[f],weak[]), hands(1,sym(-)),
freq(+), rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(fish,v,
MF[sig(dom[up],weak[up],dom[down],weak[down]), tab(dom[chest],weak[chest]),
dez(dom[a-CL],weak[a-CL]), ori(dom[k],weak[k]), hands(2,sym(+)),
freq(+), rest(+), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(),head()]);

entry(fly,v,
MF[sig(dom[forward],weak[]), tab(dom[shoulder],weak[]),
dez(dom[y-index-CL],weak[]), ori(dom[p],weak[]), hands(1,sym(-)),
freq(-), rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(give,v,
MF[sig(dom[arc-forward],weak[]), tab(dom[chest],weak[]),
dez(dom[o-CL],weak[]), ori(dom[k],weak[]), hands(1,sym(-)), freq(-),
rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);

entry(hammer,v,
MF[sig(dom[downward],weak[]), tab(dom[shoulder],weak[]),
dez(dom[a-CL],weak[]), ori(dom[k],weak[]), hands(1,sym(-)), freq(-),
```

```
rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);

entry(inform,v,
MF[sig(dom[arc-down],weak[arc-down]),
tab(dom[forehead],weak[forehead],dom[chest],weak[chest]),
dez(dom[tips-CL],weak[tips-CL],dom[5-CL],weak[5-CL]),
ori(dom[f],weak[f],dom[b],weak[b]),
hands(2,sym(+)), freq(-), rest(-), contact(-)], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);

entry(like,v,
MF[sig(dom[forward],weak[]), tab(dom[chest],weak[]),
dez(dom[curved-5-CL],weak[],dom[closed-5-CL],weak[]),
ori(dom[i],weak[],dom[o],weak[]), hands(1,sym(-)), freq(-), rest(-),
contact(+,dom[tips,on],chest)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(like,v,
MF[sig(dom[inward],weak[]), tab(dom[right-side],weak[left-side]),
 dez(dom[g-CL],weak[]), ori(dom[p],weak[p]), hands(2,sym(+)), freq(-),
rest(+), contact(+,dom[pinky,alongside],weak[pinky])], NMF[eye(),
cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(like,v,
MF[sig(dom[circular-left],weak[]), tab(dom[heart],weak[]),
dez(dom[b-CL],weak[]), ori(dom[k],weak[]), hands(1,sym(-)), freq(+),
rest(-), contact(+,dom[palm,on],weak[heart])], NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(), head()]);
```

```
entry(love,v,
MF[sig(dom[],weak[]), tab(dom[chest],weak[chest]),
dez(dom[5-CL],weak[5-CL],dom[5-CL]), ori(dom[p],weak[p]),
hands(2,sym(+)), freq(-), rest(-), contact(+,dom[wrist,atop],weak[wrist])],
NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(), head()]);

entry(love,v,
MF[sig(dom[],weak[]), tab(dom[chest],weak[chest]),
dez(dom[5-CL],weak[s-CL],dom[s-CL]), ori(dom[p],weak[p]), hands(2,sym(+)),
freq(-), rest(-), contact(+,dom[palm,atop],weak[hand])], NMF[eye(),
cheeks(), brow(), tongue(), nose(), mouth(),head()]);

entry(move,v,
MF[sig(dom[outward],weak[]), tab(dom[eyes],weak[]),
dez(dom[v-CL],weak[]), ori(dom[i],weak[],dom[o],weak[]), hands(1,sym(+)),
freq(-), rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(),
nose(), mouth(), head()]);

entry(see,v,
MF[sig(dom[outward],weak[]), tabdom[eyes],weak[]),
dez((dom[v-CL],weak[]), ori(dom[i],weak[]), hands(1,sym(+)), freq(-),
rest(-), contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(), head()]);

entry(see,v,
MF[sig(dom[outward],weak[]), tab(dom[eyes],weak[]), dez(dom[v-CL],weak[]),
ori(dom[i],weak[],dom[o],weak[]), hands(1,sym(+)), freq(-), rest(-),
contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(),
head()]);
```

```
entry(sit,v,
MF[sig(dom[outward],weak[]), tab(dom[eyes],weak[]), dez(dom[v-CL],weak[]),
ori(dom[i],weak[],dom[o],weak[]), hands(1,sym(+)), freq(-), rest(-),
contact(-)],NMF[eye(), cheeks(), brow(), tongue(), nose(), mouth(),
head()]);

entry(want,v,
MF[sig(dom[inward],weak[inward]), tab(dom[chest],weak[chest]),
dez(dom[curved-5-CL],weak[curved-5-CL]), ori(dom[b],weak[b]),
hands(2,sym(+)), freq(-), rest(-), contact(-), NMF[eye(), cheeks(),
brow(), tongue(), nose(), mouth(),head()]);

entry(wonder,v,
MF[sig(dom[circular-left],weak[circular-right]), tab(dom[forehead],weak[]),
dez(dom[g-CL],weak[]), ori(dom[f],weak[]),hands(2,sym(+)), freq(+),
rest(-),contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(),head()]);

entry(wonder,v,
MF[sig(dom[upward],weak[upward],dom[downward],weak[downward]),
tab(dom[over-head],weak[over-head]), dez(dom[5-CL],weak[5-CL]),
ori(dom[f],weak[f]),hands(2,sym(+)), freq(+),
rest(-),contact(-)], NMF[eye(), cheeks(), brow(), tongue(), nose(),
mouth(),head()]);
```

Signs for ASL Lexicon

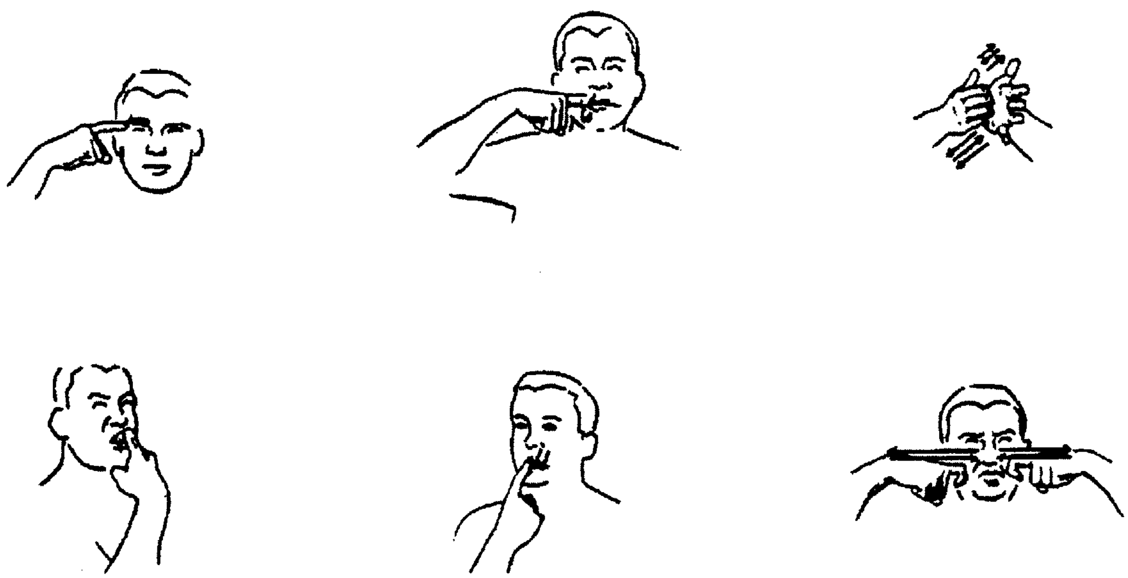


Figure A-3: **ADJECTIVES**
Row 1: black, dry, enthusiastic
Row 2: jealous, red, ugly

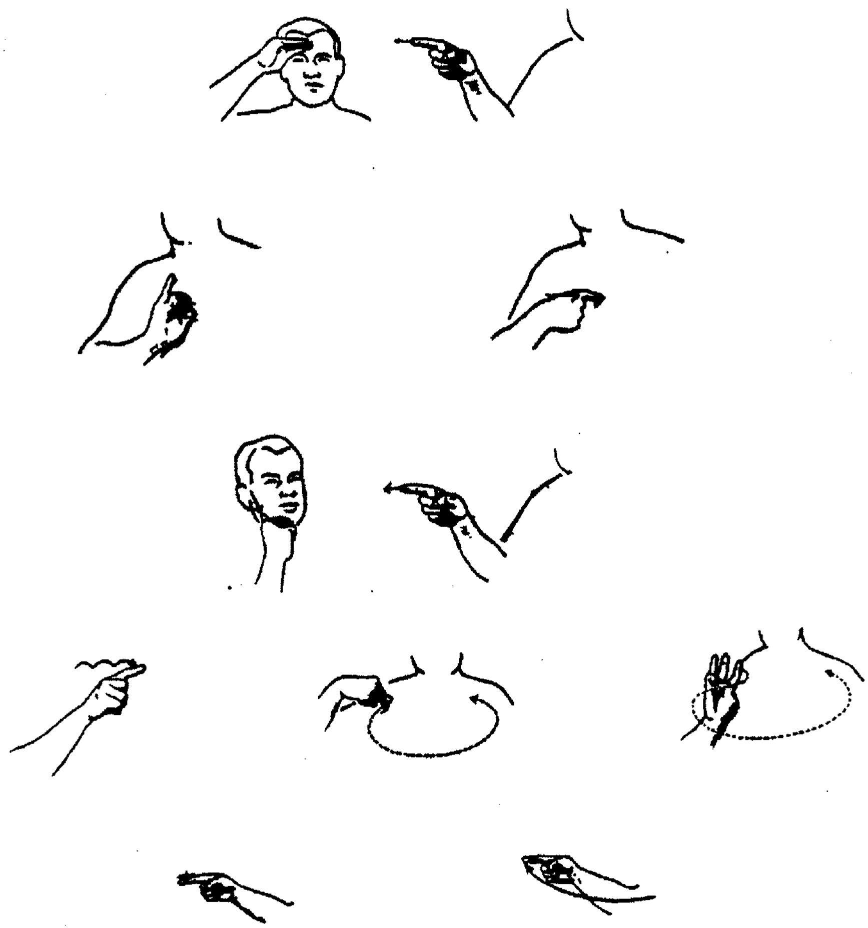


Figure A-4: **PRONOUNS**
Row 1: he (complex sign)
Row 2: I (version one), I (version two)
Row 3: she, they (version one)
Row 4: they (version two), we (version one), we (version two)
Row 5: you(version one), you (version two)

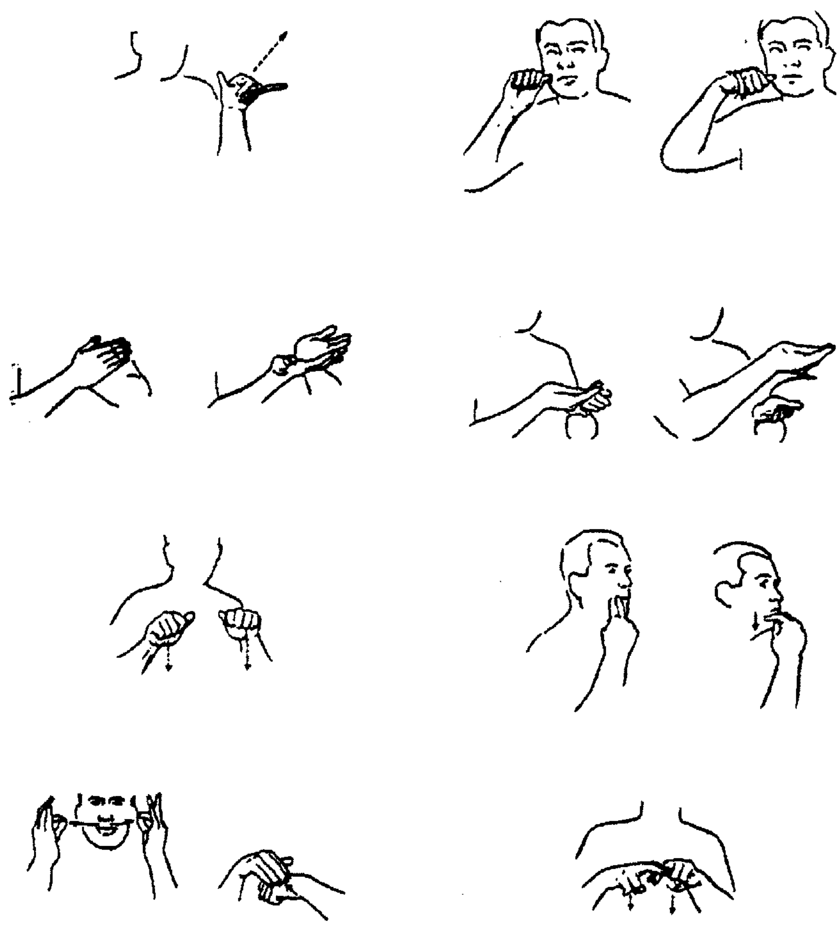
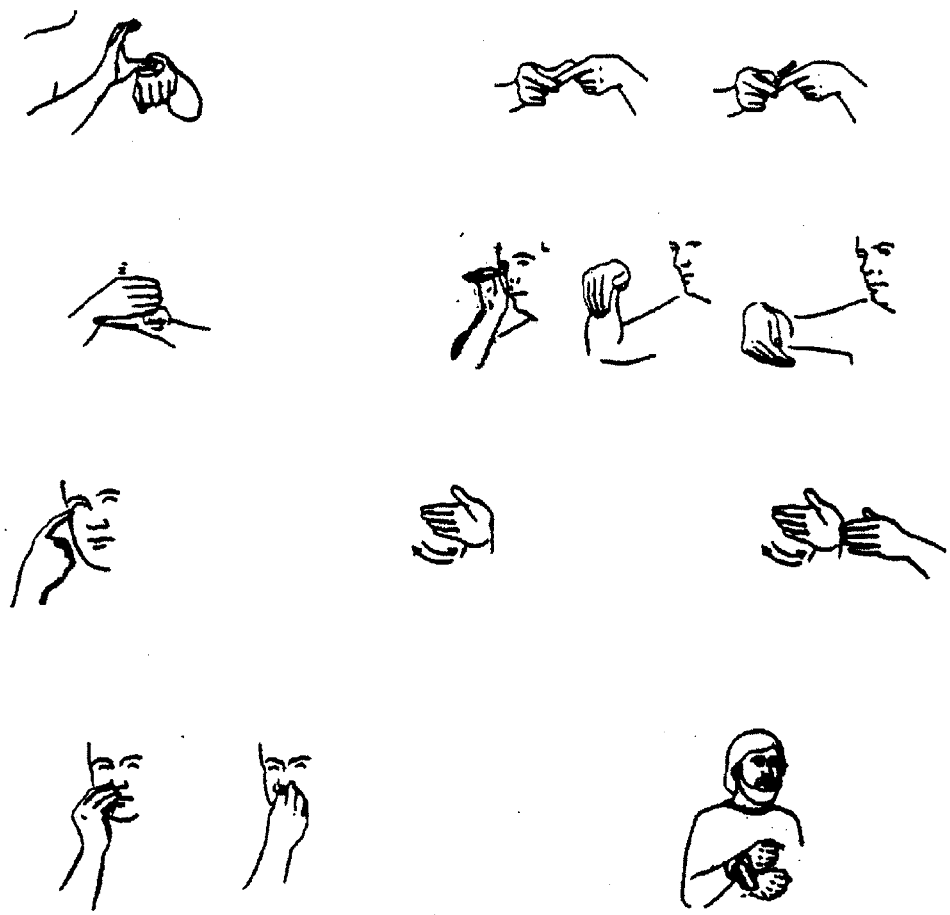
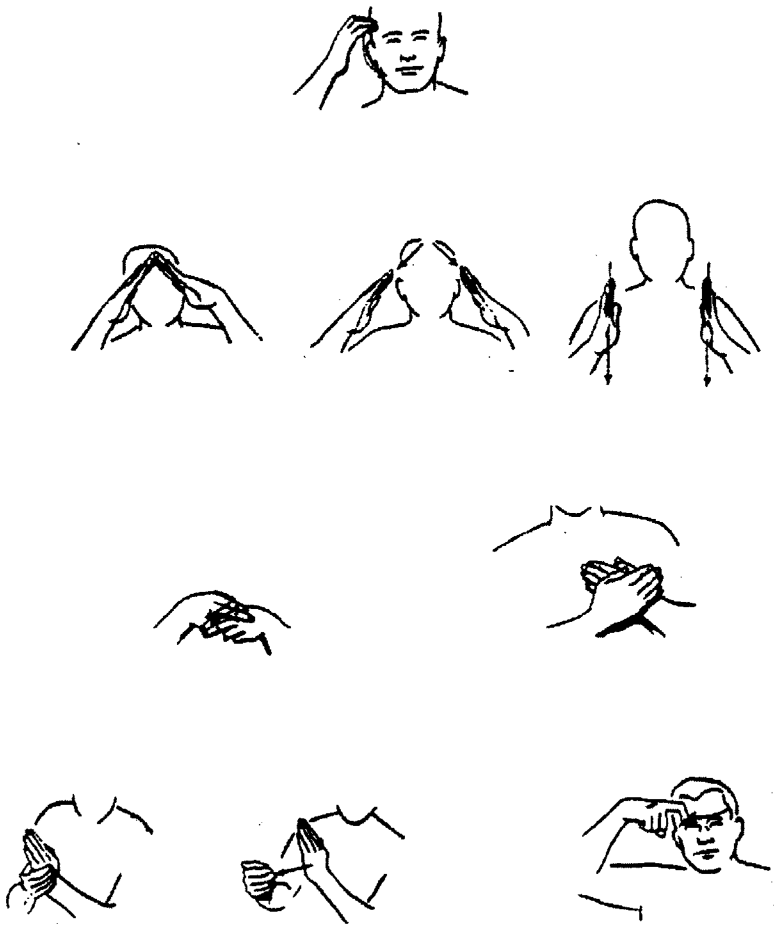


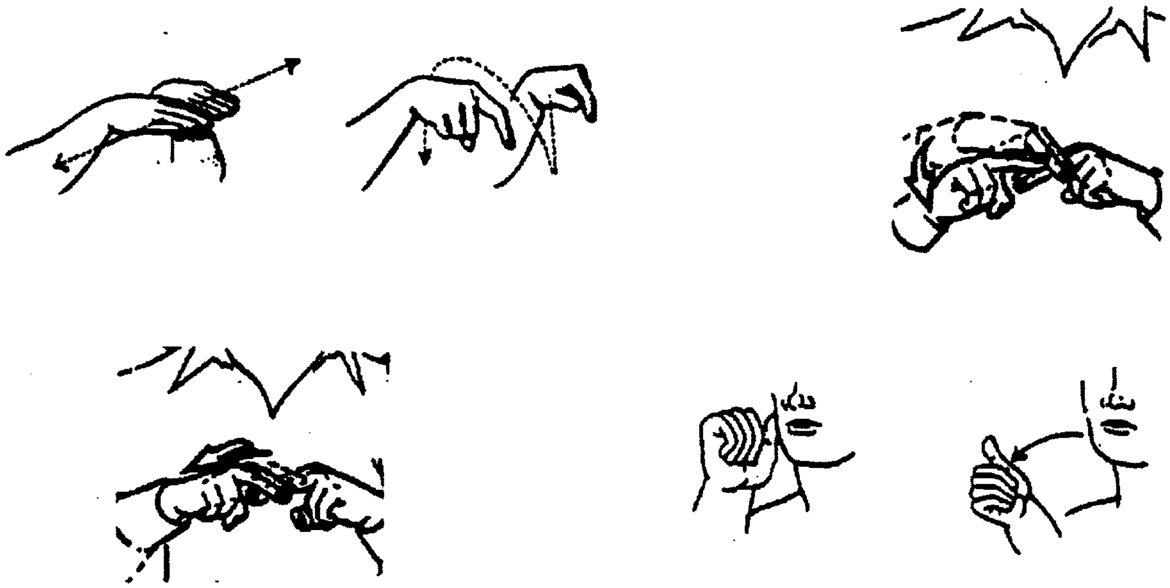
Figure A-5: **NOUNS**
Row 1: airplane, apple (complex sign)
Row 2: book (symmetrical sign), buy (complex sign)
Row 3: can, candy
Row 4: cat, chair



Row 1: chocolate, corn (complex sign)
Row 2: cup, elephant (complex sign)
Row 3: eyes, fish (version one), fish (version two)
Row 4: flower, hammer



Row 1: head
Row 2: house (complex sign)
Row 3: knife, love (version one)
Row 4: skill, summer



Row 1: table (complex sign), tape
Row 2: train, tomorrow

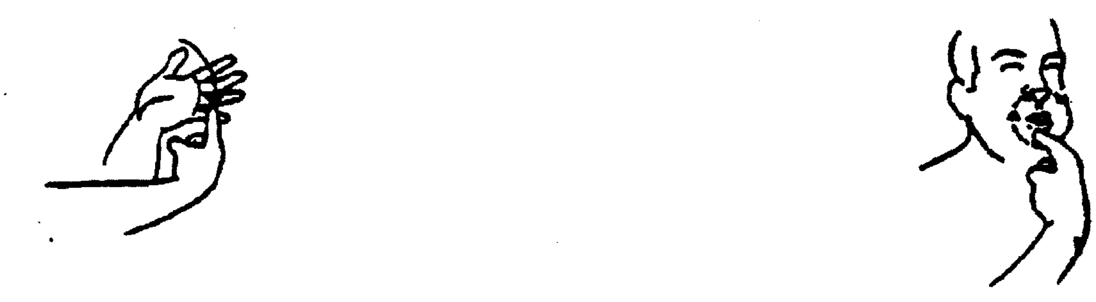


Figure A-6: **Wh-NOUNS**
Row 1: what (version one), what (version two)

Figure A-7: **ADVERBS**
Row 1: always, not (version one)
Row 2: not (version two), tommorow

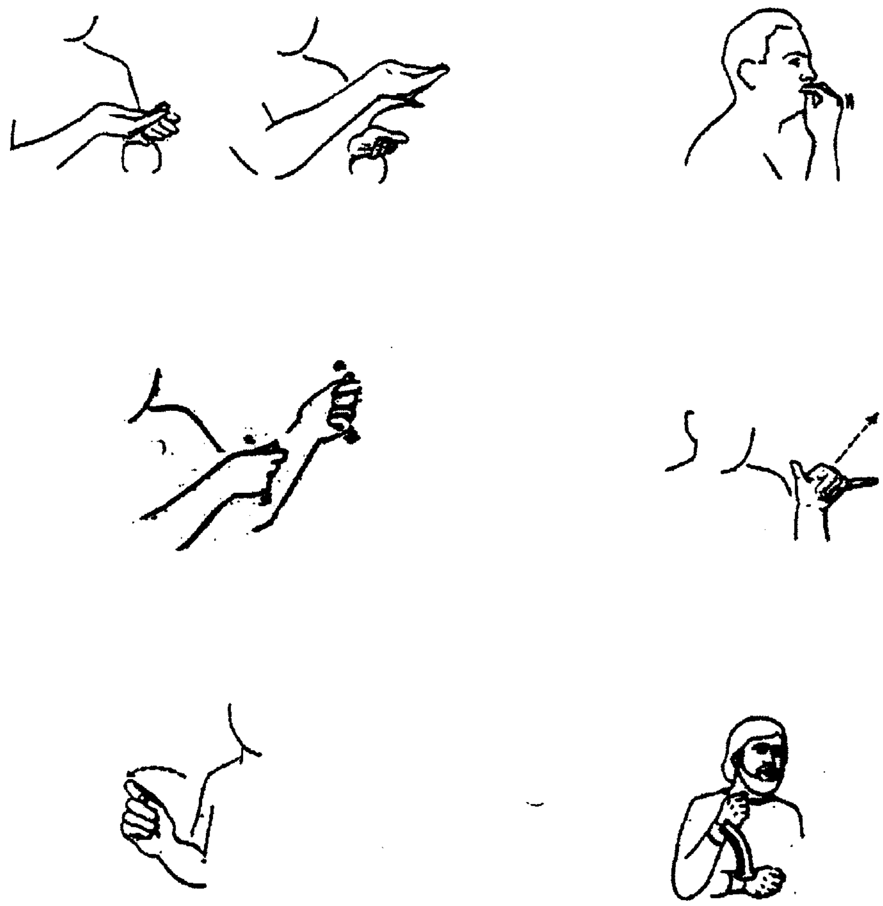


Figure A-8: **VERBS**
Row 1: buy, eat
Row 2: fish, fly
Row 3: give, hammer

Row 1: inform, like (version one)
Row 2: like (version two), like (version three)
Row 3: love (version one), love (version two)

Row 1: move
Row 2: see, sit
Row 3: want
Row 4: wonder (version one), wonder (version two)

A.4 Parse Trees of Representative ASL Phrases

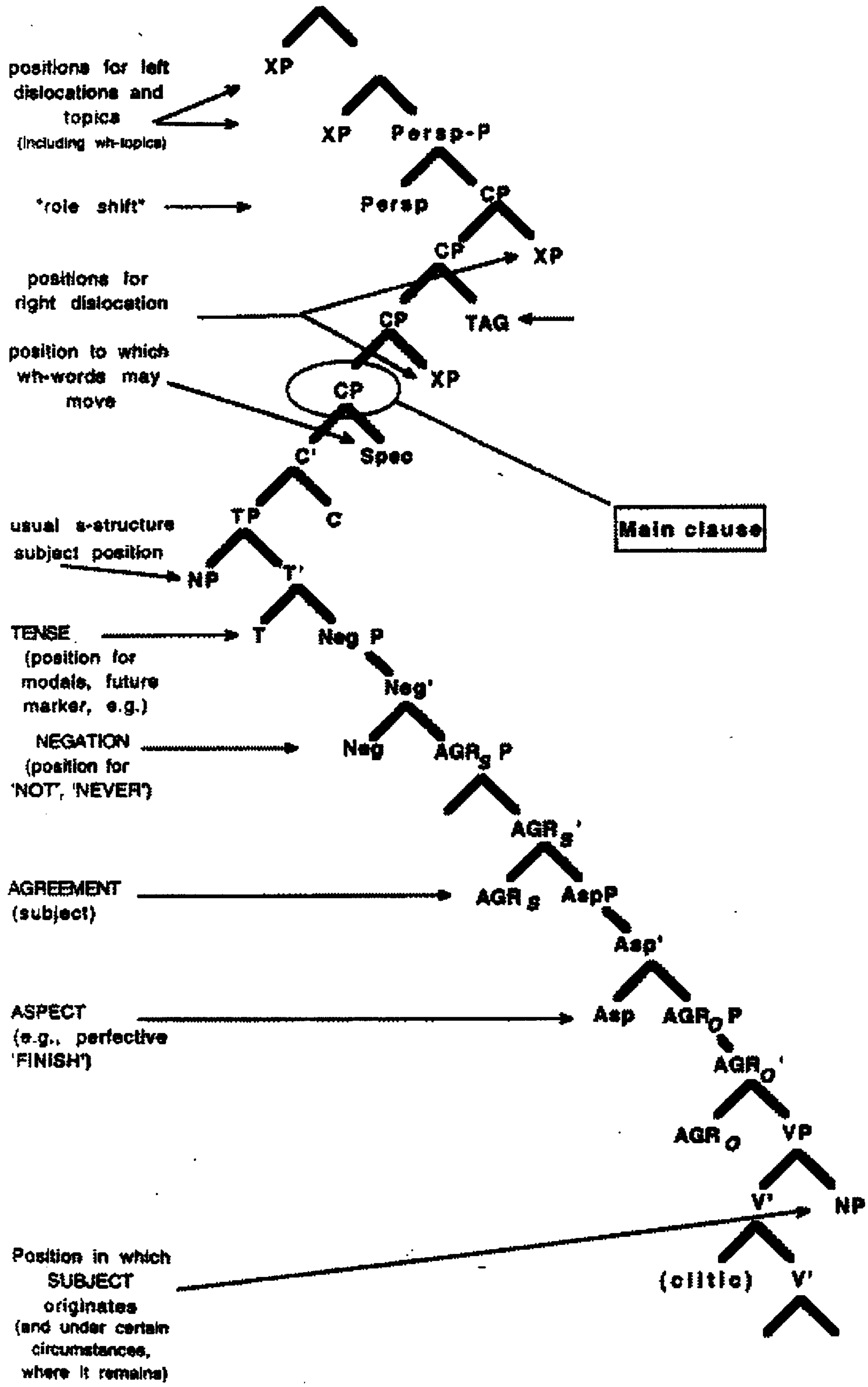


Figure A-9: ASL Phrase Structure Tree
Redrawn from [ABKN92].

Example: Negative with partial scope over phrase

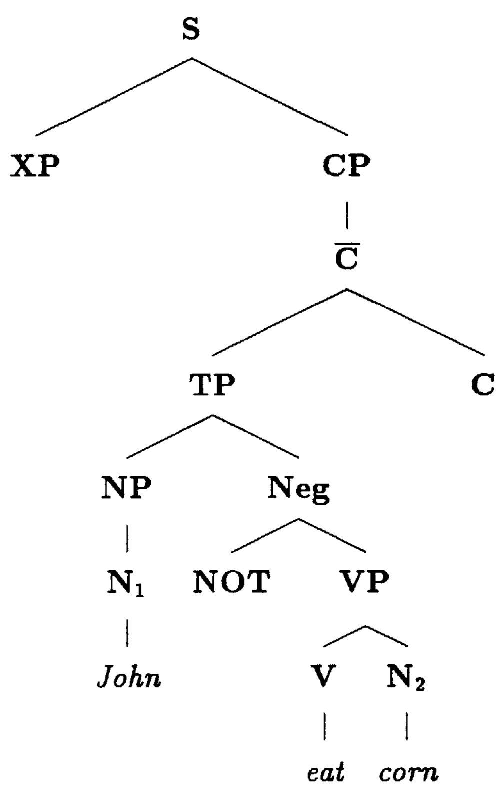
English: John does not eat corn

Gloss:

$$\text{JOHN}\ \overset{\textbf{neg}}{\overline{\textit{NOT}\quad \textit{EAT}\quad \textit{CORN}}}$$

Parser Output: ((ROOT (S (S/NEG (NP (N John))(NEG (ADV Not))(VP (V eat) (NP (N corn)))))))

ASL Tree:



Example: Topic Agreement.

English: John, (he) likes corn

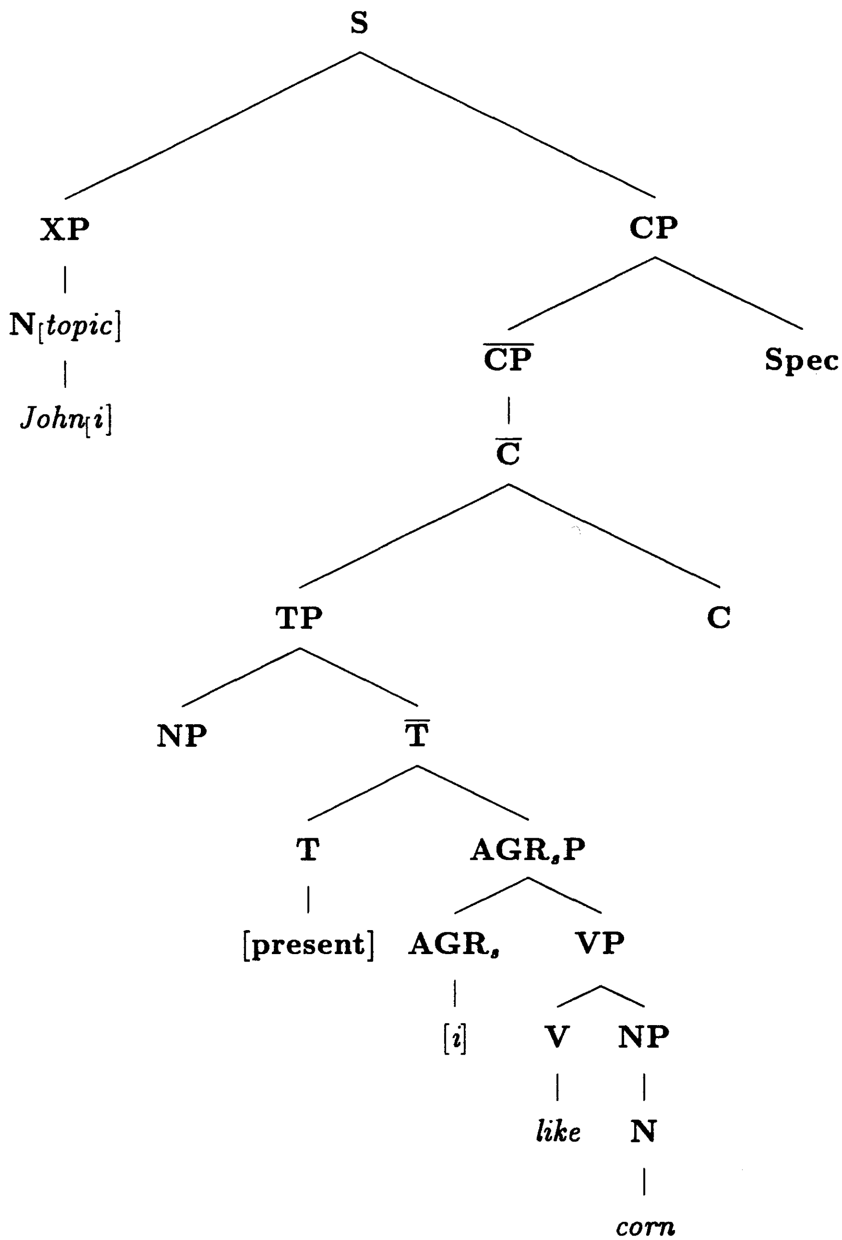
Gloss:

topic

$\overline{JOHN}$ LIKE CORN

Parser Output:((ROOT (S (S/TOPIC (TOPIC TOPIC-MARKER) (N JOHN)
(VP (V LIKE) (NP (N CORN)))))))

ASL Tree:


S
XP
CP
N[topic]
CP
Spec
John[i]
C
TP
C
NP
T
T
AGR,P
[present]
AGR,
VP
[i]
V
NP
like
N
corn

Example: Past Tense Marker with Negative.

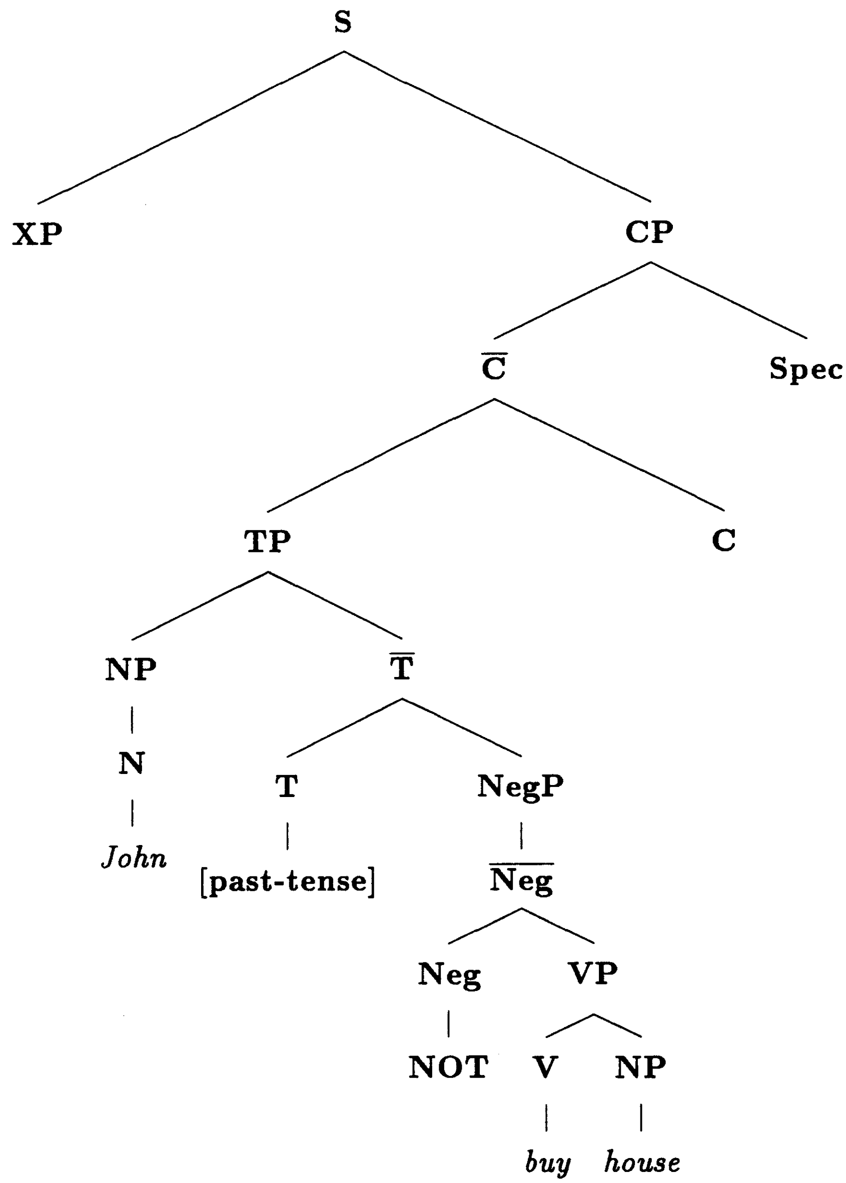
English: John didn't buy a house

Gloss:

$$\text{JOHN } \overline{[\textbf{past}-\textbf{tense}]\mathit{NOT}\quad \mathit{BUY}\quad \mathit{HOUSE}}^{\textbf{neg}}$$

Parser Output: ((ROOT (S (S/NEG (N JOHN) (LTM PAST-TENSE) (N3V (NEG NEG) (ADV NOT) (VP (V BUY) (NP (N HOUSE))))))))

ASL Tree:


S
XP
CP
C̄
Spec
TP
C
NP
T̄
N
John
T
NegP
[past-tense]
N̄eg
Neg
VP
NOT
V
NP
buy
house

Example: Lexical Tense Markers with Negative.

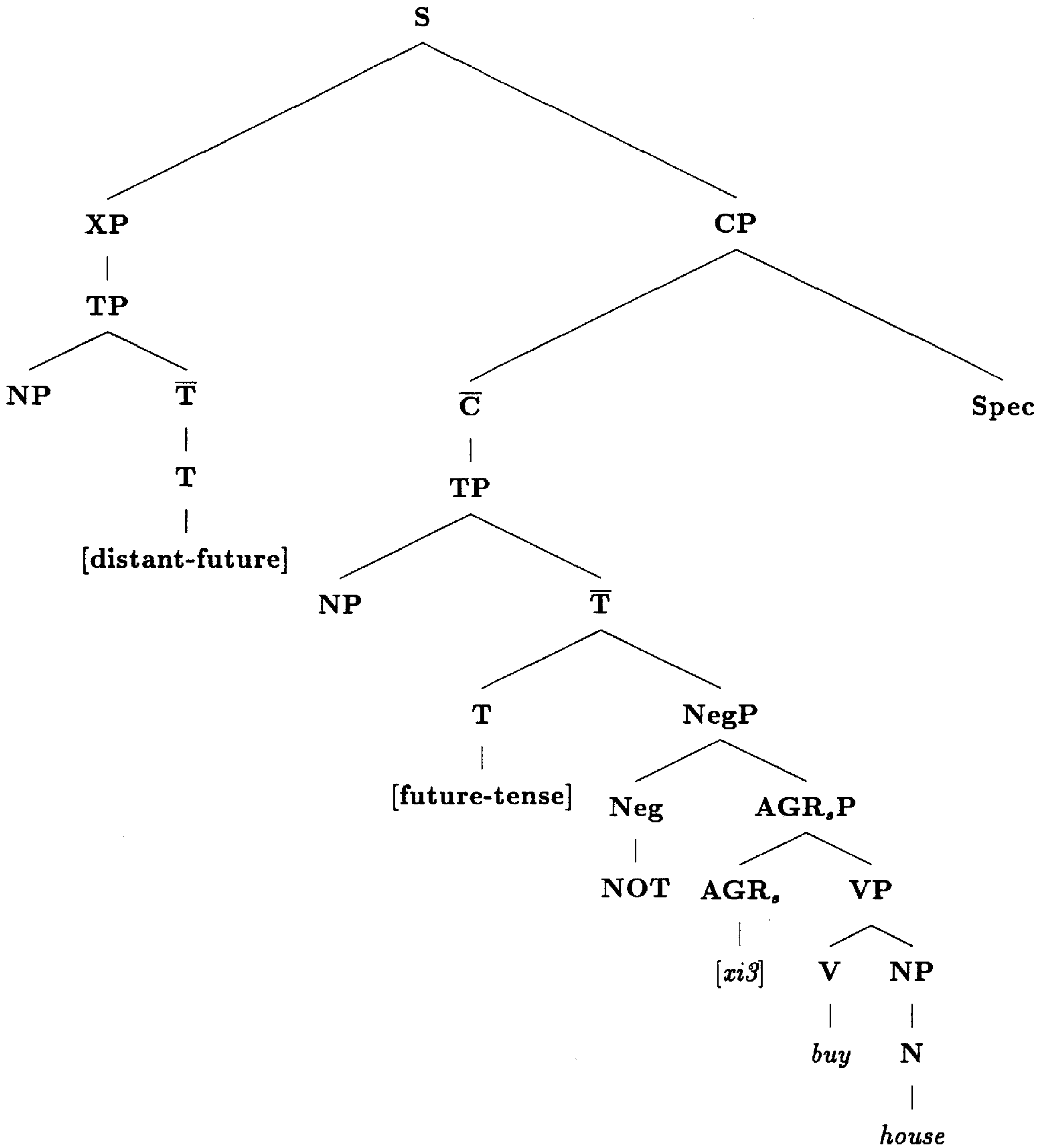
English: In the distant future, he will not buy a house

Gloss:

$$\overline{[distant-future\quad adverbial]}^{\textbf{puffed cheeks}}\quad \overline{[xi_3rd-person]\ NOT\ BUY\ HOUSE}^{\textbf{neg}}$$

Parser Output: ((ROOT (S (S/NEG (LTM DISTANT-FUTURE-TENSE) (NV4 (NEG NEG) (PRO XI3) (ADV NOT) (VP (V BUY) (NP (N HOUSE)))))))

ASL Tree:


S
XP
CP
TP
NP
T̄
Spec
C̄
T
[distant-future]
TP
NP
T̄
T
NegP
[future-tense]
Neg
AGR_sP
NOT
AGR_s
VP
[xi3]
V
NP
buy
N
house

Example: Topic agreement, Object is topic.

English: As for candy, she/he likes chocolate

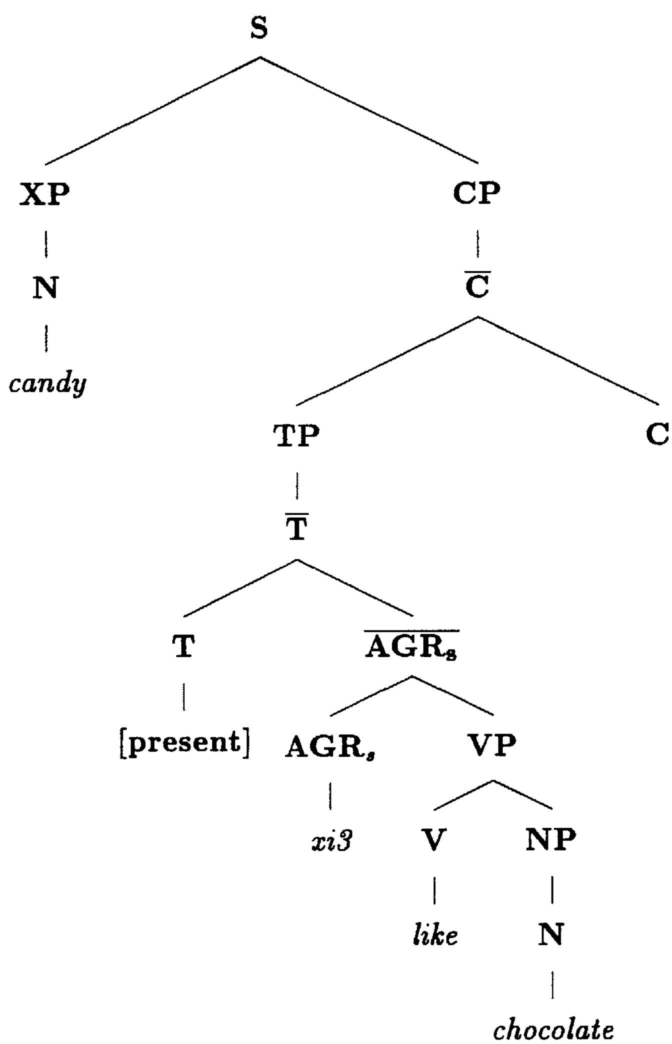
Gloss:

topic

$\overline{CANDY_{[topic]}}$ [xi3] LIKE CHOCOLATE

Parser Output: ((ROOT (S (TOPIC topic-marker)(N candy) (PRO XI3) (VP (V like) (NP (N chocolate))))))

ASL Tree:



Example: Lexical Tense Markers.

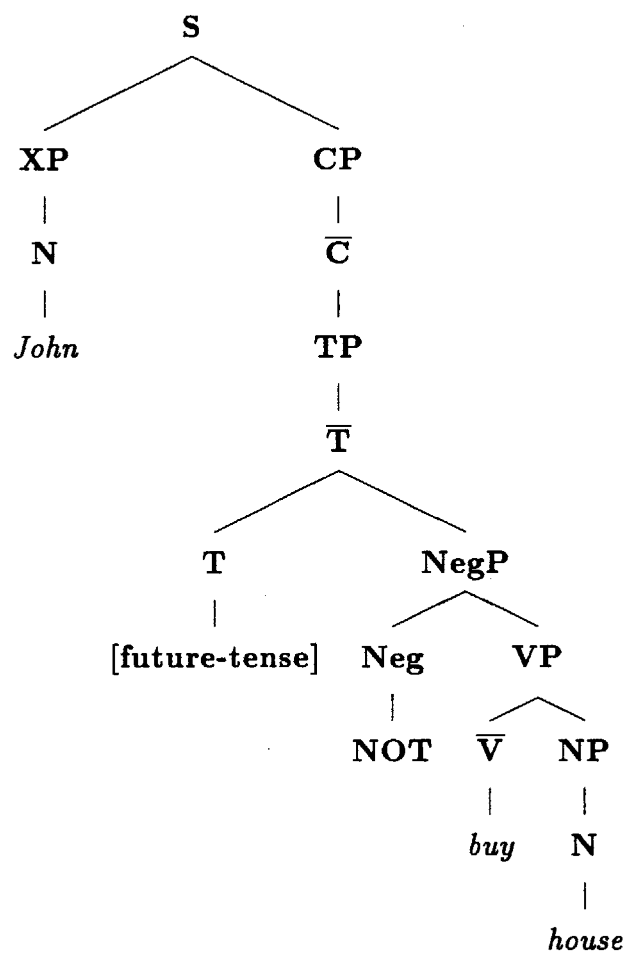
English: John will not buy a house

Gloss:

$$\text{JOHN } \overline{[\textbf{future} - \textbf{tense}] \quad \textit{NOT} \quad \textit{BUY} \quad \textit{HOUSE}}^{\textbf{neg}}$$

Parser Output: ((ROOT (S (S/NEG (N JOHN) (LTM FUTURE-TENSE) (N3V (NEG NEG) (ADV NOT) (VP (V BUY) (NP (N HOUSE))))))))

ASL Tree:



Example: Modal (non-manual lexical marker)

English: John can eat corn, he can (affirmation)

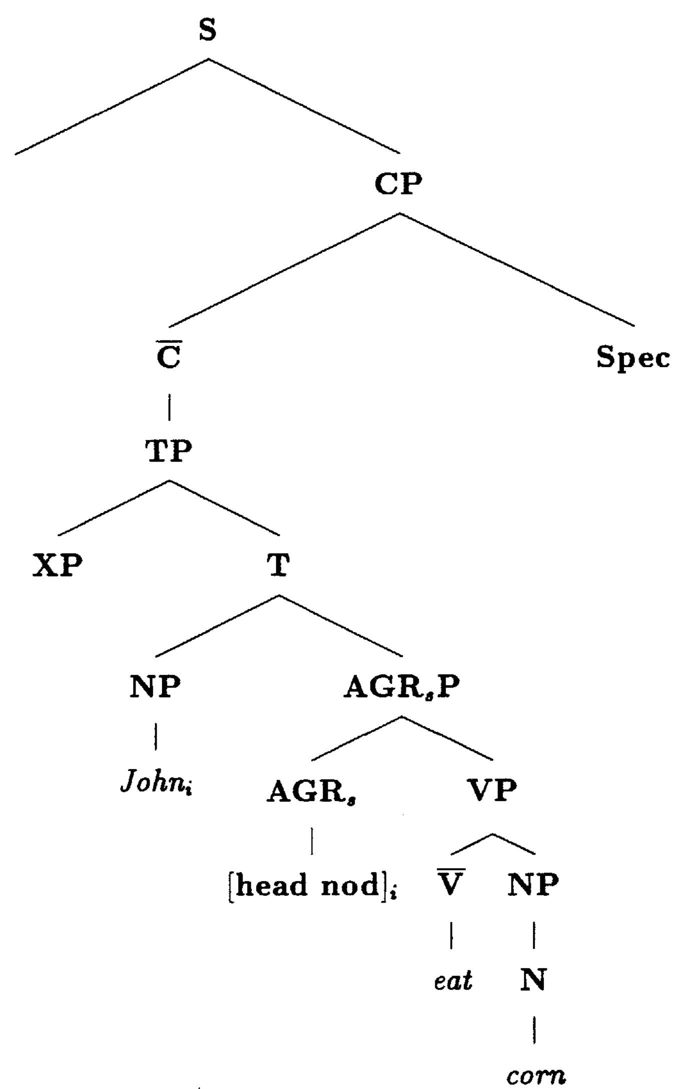
Gloss:

head nod

JOHN [CAN] $\overline{EAT\quad CORN}$

Parser Output: ((ROOT (S (NP (N JOHN)) ((MODAL can-modal) (AFFIRM head-nod)(VP (V eat) (NP (N corn)))))))

ASL Tree:



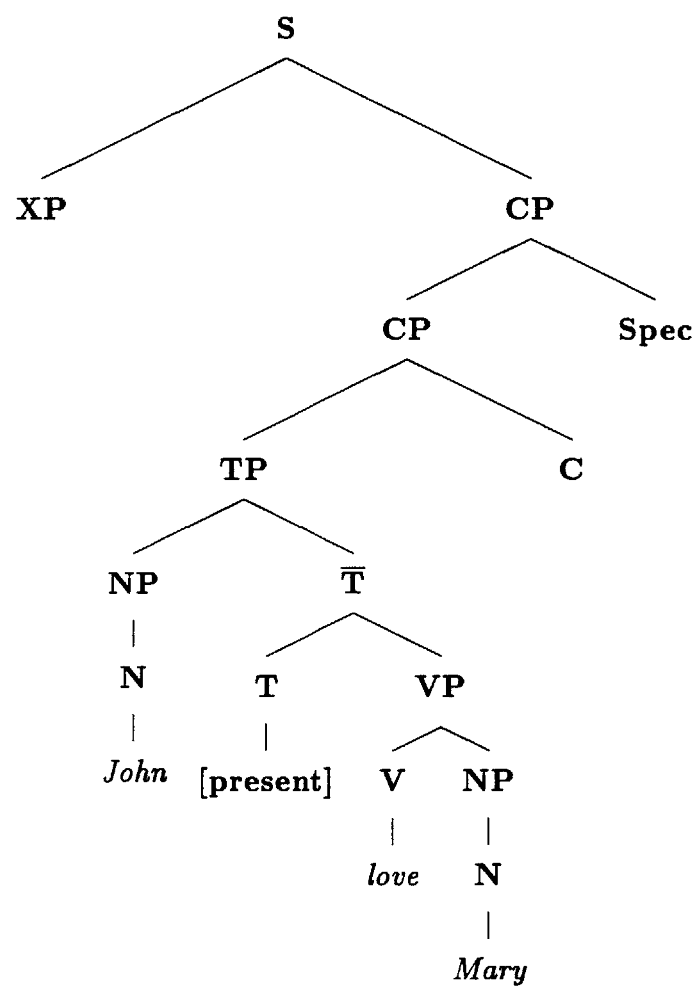
Example: Simple SVO word order sentence. English: John loves Mary.

Gloss:

JOHN LOVE MARY

Parser Output: ((ROOT (S (NP (N JOHN)) (VP (V LOVE) (NP (N MARY))))))

ASL Tree:



Example: Wh- with partial scope.

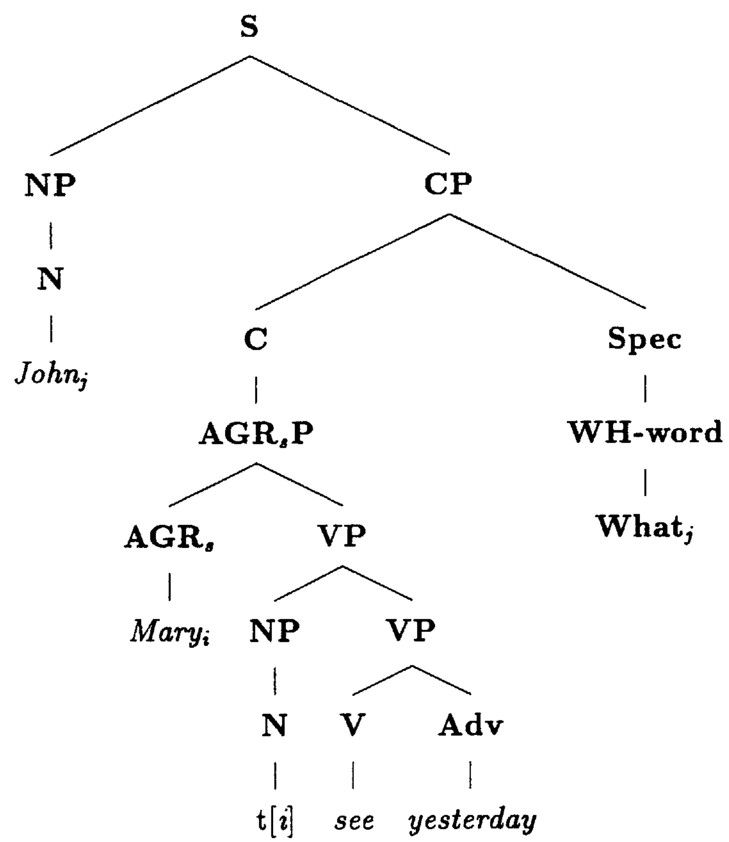
English: John wonders what Mary saw yesterday.

Gloss:

$$\text{JOHN} \quad \text{WONDER} \quad \text{MARY} \quad \overline{SEE\ [t_i]\ YESTERDAY\ WHAT_i}^{\mathbf{wh}}$$

Parser Output: ((ROOT (S (S/WH (NV (NP (N JOHN)) (VP (V WONDER) (NP (N MARY)))) (WHM WH-MARKER) (V SEE) (N YESTERDAY) (ADV WHAT)))))

ASL Tree:



Example: Topic and affirmative

English: Mary hit John, she did.

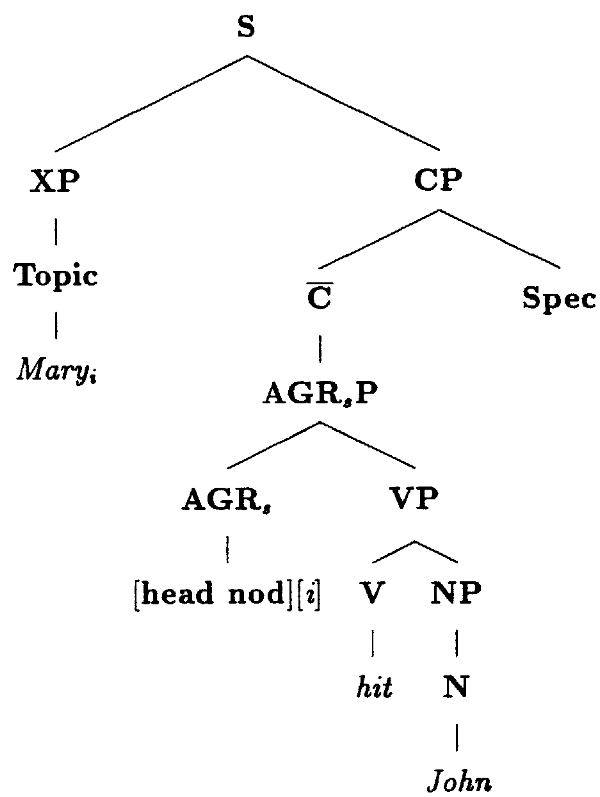
Gloss:

topic **head nod**

$\overline{MARY}$ HIT $\overline{JOHN}$

Parser Output: ((ROOT (S (S/TOPIC (TOPIC TOPIC-MARKER) (N MARY) (V LIKE) (AFFIRM HEAD-NOD) (NP (N JOHN))))))

ASL Tree:



Bibliography

[ABKN78] D. Aarons, B. Bahan, J. Kegl, and C. Neidle. *Sign Gesture and Space*, chapter Lexical Tense Markers in American Sign Language, pages 225–253. Lawrence Erlbaum Assoc., Hillside, NJ, 1978.

[ABKN92] D. Aarons, B. Bahan, J. Kegl, and C. Neidle. Clausal structure and a tier for grammatical marking in asl. *Nordic Journal of Linguistics*, 15:103–142, 1992.

[And93] Stephen Anderson. Linguistic expression and its relations to modality. In G. Coulter, editor, *Phonetics and Phonology. Current Issues in ASL Phonology*, volume 3, pages 273–290. Academic Press, Inc., 1993.

[BD] J. Benoit B. Dorr, P. Jordan. *A Survey of Current Paradigm in Machine Translation.*

[Ble93] Juliette Blevins. The nature of constraints on the nondominant hand in american sign language. In G. Coulter, editor, *Phonetics and Phonology. Current Issues in ASL Phonology*, volume 3, pages 43–62. Academic Press, Inc., 1993.

[BP76] C. Baker and C. Padden. Focusing on the nonmanual components of american sign language. In *Understanding Language through Sign Language Research*, pages 27–57, NY, September 1976. Academic Press, Inc.

[Cru86] D. A. Cruse. *Lexical Semantics.* Cambridge University Press, 1986.

[Dor93] B. Dorr. *Machine Translation. A View from the Lexicon.* The MIT Press, 1993.

[EK87] W.H. Edmonson and F. Karlsson, editors. *The Head Parameter in ASL*, Hamburg, 1987. SLR87: Papers from the Forth International Symposium on Sign Language Research, Signum Press.

[Emm93] Karen Emmorey. Processing a dynamic visual-spatial language: Psycholinguistic studies of american sign language. *Journal of Psycholinguistic Research*, 22(2):153–183, 1993.

[Fan83] Lou Fant. *The American Sign Language Phrase Book*, chapter Chapter Three. Contemporary Books, Inc., Chicago, 1983.

[Fon91] Sandiway Fong. *Computational Properties of Principle-based Grammatical Theories*. PhD thesis, Massachusetts Institute of Technology, 1991.

[GC93] S. Anderson G. Coulter. Introduction. In G. Coulter, editor, *Phonetics and Phonology. Current Issues in ASL Phonology*, volume 3, pages 1–17. Academic Press, Inc., 1993.

[Hae94] Liliane Haegeman. *Introduction to Government and Binding Theory, 2ed.* Blackwell Publishers, 1994.

[KB79] E. Klima and U. Bellugi. *The Signs of Language*. Harvard University Press, 1979.

[Lid80] Scott K. Liddell. *American Sign Language Syntax*. Mouton Publishers, 1980.

[LM91] D. Lillo-Martin. *Universal Grammar and American Sign Language. Setting the Null Argument Parameters*. Kluwer Academic Publishers, 1991.

[Nir87] S. Nirenburg, editor. *Machine Translation. Theoretical and methodological issues*. Cambridge University Press, 1987.

[NKB+93] C. Neidle, J. Kegl, B. Bahan, D. Aarons, and D. MacLaughlin. Rightward wh-movement in american sign language. In H. Van Riemsdijk, D. LeBlanc, and D. Beermann, editors, *Rightward Movement*. Academic Press, Inc., 1993.

[Pad81] C. Padden. Some arguments for syntactic patterning in american sign language. *Sign Language Studies*, pages 239–259, Fall 1981.

[Rad81] Andrew Radford. *Transformational Syntax.* Cambridge University Press, 1981.

[Rie78] L. Riekehof. *The Joy of Signing.* Gospel Publishing House, 1978.

[Ris90] E. Ristad. Computational structures of human language. Technical Report AI-TR 1260, Massachusetts Institute of Technology, 1990.

[San89] W. Sandler. *Phonological Representation of the Sign. Linearity and Nonlinearity in American Sign Language.* Foris Publications Holland, 1989.

[SK85] Judy Anne Shepard-Kegl. *Locative Relations in American Sign Language Word Formation, Syntax, and Discourse.* PhD thesis, Massachusetts Institute of Technology, 1985.

[Sta91] Thad Starner. Visual recognition of american sign language using hidden markov models. Master's thesis, Massachusetts Institute of Technology, 1991.

[Ste81] Martin Sternberg. *American Sign Language*, chapter Introduction by William Stokoe. Harper and Row, Publishers, Inc., 1981.

[Ste87] Martin Sternberg. *American Sign Language Dictionary.* HarperCollins Publisher, Inc., 1987.

[TS76] E. Newport T. Supalla. The derivation of nouns and verbs in american sign language. In *Understanding Language through Sign Language Research*, pages 91–133, NY, September 1976. Academic Press, Inc.

[Wil87] R. Wilbur. *American Sign Language: Linguistic and Applied Dimensions.* Little Brown and Co., 1987.