The Natural Classes of Two-Handed Signs
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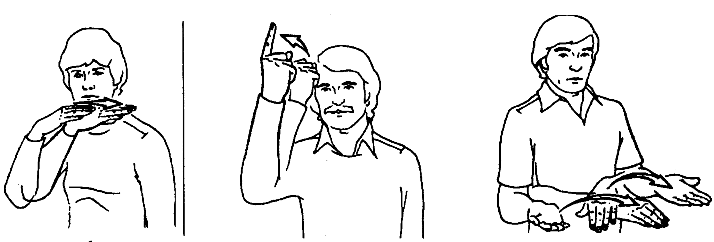
1.0 Introduction

In this paper we focus on identifying the natural classes of two-handed signs in American Sign Language (ASL). To this point, the overall goal of our work has been to develop a formal representation of signs and formal definitions of sign symmetry. This has led us in previous work (Uyechi & Toole 1997) to argue for a set of formal binary symmetry features for each of the parameters of a sign: namely, handshape, orientation, location, and movement. In this paper we take this approach one step further. We argue that the symmetry features are not independent - rather, they are related by a feature hierarchy. Recognizing this interdependency leads us to a proposal for the natural classes of two-handed signs that not only accounts for the distribution of two-handed signs but also accounts for some properties of diachronic change.

We begin by giving a brief introduction to the basic properties of two-handed signs and introduce the two puzzles that motivate our work. We then review the symmetry features introduced in Uyechi & Toole (1997) and introduce our approach to natural classes in ASL.

2.0 Basic Properties of Signs

Signs are described in terms of four parameters: handshape, location, orientation, and movement. Following Stack (1988) and Hayes (1993), we take the view that only handshape, location and orientation are phonological primitives. On this analysis, movement is not a primitive. Rather, it is derived from changes in the other three parameters, as illustrated by the signs in (1).



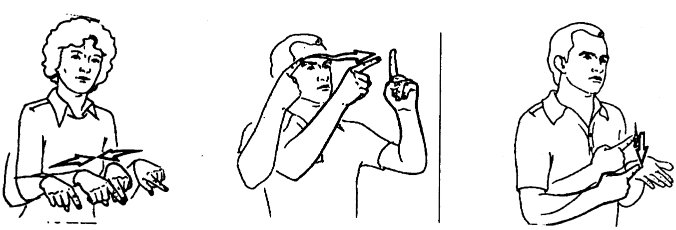
1 a. LIE[1] b. UNDERSTAND c. DIE

To articulate (1a), the hand starts at one side of the chin and ends at the other side. This is an example of a change in location. In (1b) the hand starts in a position in which all the fingers and thumb are folded into a fist with the hand held at the side of the signer's head and the palm of the hand facing towards the signer. To articulate the sign the index finger is extended until it points straight up. This is an example of a change in handshape. To articulate (1c) the hands start in a position in which one palm faces up and the other down. The hands are then rotated 180 degrees so that each palm faces the other way. This is an example of a change in orientation. All movements articulated in monomorphemic lexicalized signs can be represented by these three components of movement: change in location, change in handshape, and change in orientation (Uyechi 1995).

The earliest typology of two-handed signs is Battison's (1978) three-way typology. Although we note elsewhere that Battison's definitions are too informal and imprecise to form the basis of an adequate typology (see Toole & Uyechi 1995, Uyechi & Toole 1997), it is a well-known system that provides a convenient way to describe two-handed signs. For this reason, we informally introduce Battison's typology and use it as a reference system in the remainder of this paper.

Briefly, Battison classifies two-handed signs into one of three classes: Type 1, Type 2, and Type 3 signs. In a Type 1 sign, (2a), both hands have the same handshape, orientation, and location, and both hands move. In a Type 2 sign, (2b), both hands have the same handshape, but only one hand moves. In a Type 3 sign, (2c), the hands have different handshapes and only one hand moves.

2.



a. ALIKE　　b. GOAL　　c. DISCUSS

3.0 The puzzles

3.1 Puzzle 1: Diachronic Variation

Previous research has noted that some two-handed signs exhibit a diachronic change towards more symmetrical forms (Frishberg 1975, Sandler 1993, Brentari 1995). For example, the original sign for WHISKEY is a Type 3 sign, as shown in (3a). The handshapes are different, and only one hand moves. However, the more common articulation of the sign is now the Type 2 pronunciation in (3b): in this sign the handshapes are the same, although only one hand moves.

3.

a. WHISKEY[Type 3]
older version

b. WHISKEY[Type 2]
newer version

Of interest to us is the fact that many Type 3 signs do NOT undergo this migration. For example, the sign in (2c), DISCUSS, is a Type 3 sign - the hands have different handshapes and only one hand moves - and it gives no indication of migrating to a Type 2 sign. Rather, it is clearly a stable Type 3 sign.

The puzzling behavior we need to address is how to predict which Type 3 signs are "stable" Type 3 signs and which are likely to migrate towards the more symmetrical form of a Type 2 sign. The general classes of Battison's typology and similar proposals such as Sandler (1993) and van der Hulst (1993) cannot account for this important difference in Type 3 signs.

3.2 Puzzle 2: The Distribution of Two-handed Signs.

In previous work we provided a formal definition of symmetry for each of the four parameters of a sign (Uyechi & Toole 1997). We proposed that each sign can be classified according to whether or not it has symmetric handshape, symmetric location, symmetric orientation, and symmetric movement. A consequence of this approach is that there are sixteen logically possible combinations of symmetry features, and therefore, sixteen possible classes of two-handed signs.

However, in a random survey of over 100 two-handed signs, only five of these logical possibilities are in evidence. These classes are shown in (4), where a '+' indicates that this parameter of the sign is symmetric. A representative example from each class is given in (5). The second puzzle, then, is to account for this empirical distribution of signs.

4.

	HS	LOC	OR	mov		
A	+	+	+	+	ALIKE	Maximally symmetric
B	+	+	+	-	RIGHT	
C	+	+	-	-	SLOW	
D	+	-	-	-	GOAL	
E	-	-	-	-	DISCUSS	Maximally non-symmetric

5.

a. ALIKE b . RIGHT c. SLOW d. GOAL e. DISCUSS

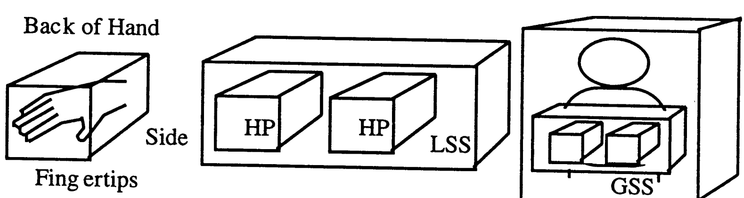
4.0 Symmetry Features

In order to account for the two puzzles introduced in the previous section, we begin by introducing Uyechi's (1996) geometry-based model of signs and Uyechi & Toole's (1997) formalization of symmetry. Following this we introduce the Feature Symmetry Hierarchy which we use to account for the two puzzles.

4.1 The Geometry-based Model

The geometry-based model of sign phonology is based on a three-dimensional rectangular representation of signing space. As illustrated in (6), the hands are represented as hand prisms which are embedded in rectangular prisms of signing space. Monomorphemic signs are articulated in local signing space, (6b), which is in turn embedded in global signing space, (6c). Morphologically complex signs are specified for positions in both local and global signing space. At an even higher level of representation, discourse is represented as instances of global signing space embedded in a discourse signing space. Of interest here is the representation of monomorphemic signs, hence the discussion will focus on the relation between the hand prisms and local signing space

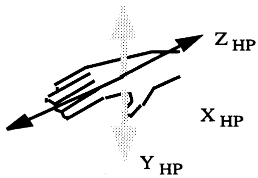
6. Geometry Based Representation of Articulators and Signing Space

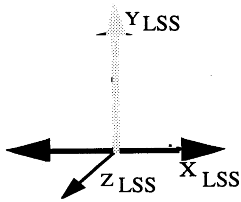


a. Hand Prism b. Local Signing Space c. Global Signing Space

In particular, we focus on the relation between the hand prisms within local signing space, and global signing space. The position of local signing space (LSS) does not change during the articulation of a monomorphemic sign, rather, it carves out the relevant part of signing space. The places of local signing space then provide reference planes for determining the relative posture of the hands. Movement of the hands is represented as changes in position of the hand prisms within local signing space.

Finally, we note that the dimensions of the hand prisms, local signing space, and global signing space can also be represented in terms of the axes which define the prisms. For example, the dimensions of the hand prism in (6a) can be represented by the three axes as in (7a). The dimensions of the local signing space in (6b) can be represented as in (7b).





7. a. Hand Prism b. Local Signing Space

Using this system we are able to formalize symmetry for each of the components of a sign, namely handshape, location, orientation, and movement

4.2 Formalizing Symmetry

In this section we use the constructs of the geometry-based model to formalize the definition of symmetry. We define symmetry for each of the components of the sign described above, namely handshape, location, orientation, and movement. The brief definitions we give here are based on the more detailed definitions given in Uyechi & Toole (1997).

HANDSHAPE:

Handshape is symmetrical if both hands have the same handshape. For example, (8a) is articulated with both hands in the same configuration. In contrast in (8b) the moving hand has a different configuration from the non-moving hand. Hence (8a) has symmetrical handshape, but (8b) does not.

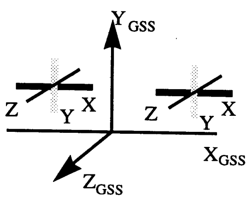

8. a. ALIKE (+symHS) b. DISCUSS (-symHS)

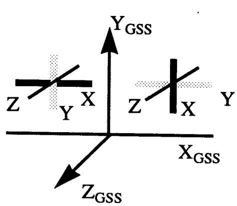
ORIENTATION:

A sign has symmetric orientation if it meets the constraint given in (9) (where "corresponding axes" refers to the X-axes of both hand prisms, the Y-axes of both hand prisms, and the Z- axes of both hand prisms).

9. Constraint on Orientation in Two-Handed Signs
In a two-handed sign, corresponding axes must be parallel.

For example, in (10a) all three axes are parallel to each other throughout the articulation of the sign. In contrast, in (10b) only two sets of corresponding axes are perpendicular to each other. Hence, (10a) is articulated with symmetric orientation, but (10b) is not.[2]





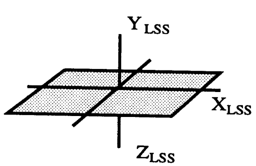
10. a. ALIKE (+symOR) b. GOAL (-symOR)

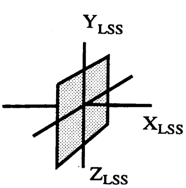
LOCATION:

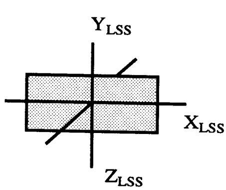
Using the relative position of the hand prisms in local signing space, we define symmetric location in (11) where we use the formal definition of the "origin" of the hand prism as the point at which the X-, Y-, and Z- axes of the hand prism intersect each other.

11. A sign has symmetrical location if, at some point in the sign, the location of the origin of one hand prism is a reflection of the location of the origin of the other hand about one plane of symmetry in LSS.

The planes of symmetry for the location parameter are the planes defined by the axes of local signing space, namely, the X-Z plane, the Y-Z plane, and the X-Y plane, illustrated in (12).

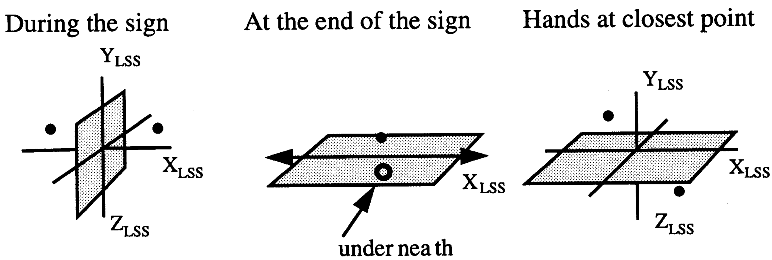






12. a. X-Z place b. Y-Z plane c. X-Y plane

For example, in the sign ALIKE, (2c), the location of the hands is symmetric throughout the articulation of the sign. In (13a) we illustrate this by showing the origins of the hands relative to each other at the beginning of the sign. As is evident from this diagram the origins of the hand prisms are reflected about the centre (Y-Z) plane. In (13b), the locations are symmetric only at the end of the gesture because one hand is static throughout the articulation of the sign. At the end of the gesture the origins of both hand prisms are reflected about the base (X-Z) plane. In (13c), even at the points where the hands are closest, at the end of the sign, the origins of the hand prisms are skewed with respect to the base plane, and are not reflected about either of the other planes. Hence (13a) and (13b) are articulated with symmetric location but (13c) is not.



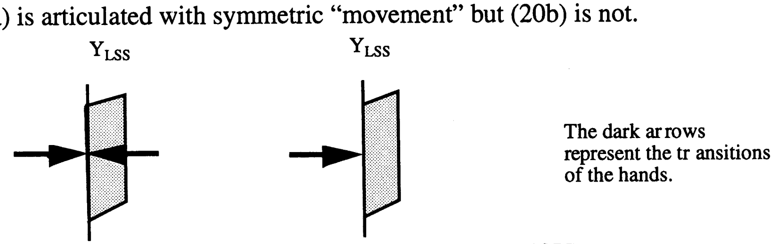
13. a. ALIKE (+symLOC)b. RIGHT (+symLOC)c. DISCUSS (-symLOC)

MOVEMENT:

In the geometry-based system "movement" is represented as a transition in one of the primary components. Specifically, movement is represented as either a change in handshape, change in location, or change in orientation. Hence, symmetric movement is defined as in (14).

14. A sign has symmetric "movement" if the transition(s) of the hands are a reflection about a plane of symmetry in LSS.

For example, both signs in (15) are articulated with a change in location. The movement vectors in (15a) are reflections about the centre plane. In contrast, only one hand moves in (15b), so the vectors are not reflections about any plane. Hence (20a) is articulated with symmetric "movement" but (20b) is not.



15. a. ALIKE(+symMOV) b. GOAL(-symMOV)

In sum, for *each* of the four parameters, a sign can be classified as symmetric or non-symmetric. Having established the required background, we now return to the two puzzles that motivate our work.

5.0 Accounting for the Puzzles

To account for the two puzzles introduced in section (3.0), we propose that the symmetry of each feature is not independent. Rather, the symmetry features are related by the Feature Symmetry Hierarchy in (16). In this hierarchy, the symmetry of any feature assumes the symmetry of all features to its left. Thus, if a sign has symmetric movement, then it necessarily has symmetric handshape, orientation, and location. If a sign has symmetric location, then it necessarily has symmetric orientation and handshape, and so on.

16.

Feature Symmetry Hierarchy
HS > OR > LOC > mov

The hierarchy provides both explanatory and predictive power for the analysis of two-handed signs: it explains the occurrence of only five of the sixteen possible classes of two-handed signs, and it provides the basis for predicting the migration of two-handed signs towards more symmetric forms. We start by describing the explanatory power of the hierarchy.

The five classes allowed by the hierarchy are listed in (17). Simply stated, no other classes meet the requirements of the Feature Symmetry hierarchy.

17.

class	HS	LOC	OR	mov		
A	+	+	+	+	ALIKE	Maximally symmetric
B	+	+	+	-	RIGHT	
C	+	+	-	-	SLOW	
D	+	-	-	-	GOAL	
E	-	-	-	-	DISCUSS	Maximally non-symmetric

Comparing these classes with those presented in section 3.0, we see that the predicted classes in (17) correspond exactly with the classes in (4) that emerged from an examination of over one hundred randomly chosen signs. Hence, the hierarchy provides an account of the empirical distribution of data.

The predictive power of the hierarchy is illustrated by applying it to the puzzling data from diachronic change described in section 3.1. Specifically, we address the question of why some Type 3 signs undergo diachronic change and become Type 2 signs (WHISKEY), whereas other do not (DISCUSS). Again, the hierarchy accounts for this problem. In (18) we compare the symmetry features for the two signs, WHISKEY and DISCUSS.

18.

	HS	LOC	OR	mov
DISCUSS S	-	-	-	-
WHISKEY S	-	+	+	-

Although both of these signs are classified as Type 3 signs under Battison's typology, when presented in terms of their symmetry features these signs are clearly distinct types of signs. The symmetry features of DISCUSS (18a), indicate that none of its parameters are symmetric. This is a classification that is consistent with the Feature Symmetry hierarchy: thus predicting that the signs is stable and unlikely to undergo diachronic change.

In contrast, the configuration of the symmetry features for WHISKEY, (18b), violates the Symmetry Feature hierarchy. It has symmetric location and orientation but not symmetric handshape. Because the hierarchy requires that handshape be symmetric if location and orientation are symmetric, it predicts that the form in (18b) is unstable; hand shape must be symmetric in order for this sign to be consistent with the hierarchy. In fact, the more recent form of WHISKEY is one in which the static hand has the same handshape as the moving handshape. Having acquired symmetric handshape, WHISKEY now meets the Feature Symmetry hierarchy.

This prediction holds of other signs that have entered into the lexicon, e.g., WORLD and RESIDENTIAL-SCHOOL. In their original form these signs have the same symmetry features as WHISKEY and do not adhere to the Feature Symmetry hierarchy. Each of these signs has undergone changes that parallel the changes to WHISKEY so that each is now consistent with the hierarchy.

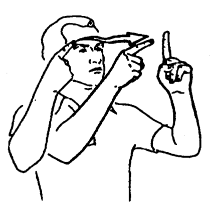
In addition, there is cross-linguistic evidence to support this view. In (19) we show both old and new versions for the sign for TRAIN in Italian Sign Language (LIS) (Radutzky 1990). The older version violates the Feature Symmetry hierarchy; it has symmetric location and orientation but not symmetric handshape. The newer form of the sign has acquired symmetric handshape and is now consistent with the hierarchy. We claim, then, that signs that are not consistent with the feature hierarchy are unstable and are likely to undergo changes that bring them into line with the hierarchy.

19.  

a. TRAIN (old) b. TRAIN (new)

Hence, the feature hierarchy explains the presence of precisely five classes of signs in the data as well as correctly predicting the migration of two-handed signs towards more symmetric forms. Thus, we present these five classes as candidates for the natural classes of two-handed signs.

As natural classes, we would expect other phonological processes to be sensitive to them. Indeed this is the case. As illustrated in (20), the feature hierarchy and the natural classes of two-handed signs that it predicts account for the synchronic alternation noted by Uyechi & Toole (1997): namely, that some Type 2 signs have a type 1 pronunciation. In other words, some signs that are articulated with the hands in the same handshape but one hand static can also be articulated with both hands moving symmetrically. For example, RIGHT, shown in (20a), can be articulated with one hand static, or with both hands moving symmetrically. In contrast, a Type 2 sign such as (20b) does not have a Type 1 pronunciation.

20 a. RIGHT b. GOAL

Again, comparing the symmetry features of the Type 2 signs reveals a significant underlying difference. As shown in (21), all but the movement parameters are symmetric for RIGHT, (21b), whereas only the handshape parameter for GOAL,(21a) is symmetric.

21.

		HS	OR	LOC	mov
a.	GOAL	+	-	-	-
b t	RIGHT	+	+	+	-

Hence, the feature hierarchy again provides an explanation for the alternation for

RIGHT, and the lack of alternation for GOAL. For RIGHT, all of the parameters that are lower in the feature hierarchy are symmetric, so it can acquire symmetric movement and still be consistent with the hierarchy. In contrast, GOAL lacks symmetric location and orientation. It cannot acquire symmetric movement because this would make the sign inconsistent with the hierarchy (handshape, location, and orientation must be symmetric before movement can be symmetric).

In sum, in this section we have introduced a symmetry hierarchy that dramatically restricts the gestures that can be valid two-handed signs. This hierarchy predicts that there are five classes of signs, which we identify as class A-class E. In class A all the parameters of a signs are symmetric, in class B all parameters except movement are symmetric, in class C only handshape and orientation are symmetric, in class D only handshape is symmetric. Finally, in class E signs none of the parameters are symmetric. As well as accounting for the characteristics of two-handed signs and excluding gestures which are not natural two-handed signs, we found that the hierarchy also provides insight into cases of diachronic change and synchronic variation. Furthermore, there is cross-linguistic evidence to support this claim.

6.0 Some Consequences for Universal Phonology

Our approach raises interesting questions with respect to universal phonology. Specifically, the sign symmetry features that we are proposing are associated with a whole sign gesture. Yet, a large number of sign phonology proposals support the idea that there is a one to one mapping between the sign gesture and the syllable. This suggests that for sign language some features are associated with the *syllable*. This is a highly irregular finding from the perspective of spoken language phonology. However, we believe it is premature to focus on these apparent differences between spoken language and signed languages. Rather, a more productive approach is to continue to study signed languages using theories and constructs which seem most relevant to the visual mode.

As we have seen, the geometry-based approach we take has allowed us to identify classes which (i) reflect sign distribution, and (ii) which are relevant to phonological processes in ASL. We believe the best approach is to study sign phonology independently of spoken language phonology so that ultimately each will provide independent evident for a *truly* universal theory of phonology.

Endnotes:

1. In this paper we follow the convention of glossing signs with small capitals.

2. One additional point needs to be made with respect to symmetric orientation. First, when articulating a sign like (RIGHT/CORRECT), the axes of the hands

are skewed articulatorily. This is arguably induced by the physiology of the hands. The environment for this adjustment is restricted, and shifting the hands so the axes are aligned does not change the meaning of the sign (as happens for some signs, e.g., NAME). Hence, this variation can arguably be captured by a phonetic adjustment rule.With respect to the phonology, the orientation for these signs is symmetric.

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(Pictures from Humphries, Padden, and O'Rourke (1980), illustrated by Frank Paul.)