Movement and Location Notation for American Sign Language

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This paper outlines a hybrid notational system for transcribing the movement and location parameters of signs in American Sign Language (ASL). This system is designed to aid in the translation of ASL to English. The paper begins by summarizing the current translation technology, focusing on the instrumentation-based approach favored by the New Jersey Institute of Technology. This approach uses a handshape recognizer and an inertial positioning system to identify the handshape, orientation, movement, and location components of ASL. The nonmanual component can not be measured with the current system. Of these five parameters, only handshape and orientation are defined adequately by existing notational systems for identification by instrument-based approaches. The accepted linguistic descriptions (the Stokoe and Movement-Hold systems) and several notational systems (HamNoSys, Labanotation, and Farris) are surveyed, focusing on the assets and deficits of their methods for representing movement and location with respect to the inertial positioning system. A hybrid notational system for movement and location parameters, based on the organization of data imposed by the instrumentation used in its collection, is outlined.

0.0 Introduction

Design of the Inertial Positioning System component of the American Sign Language Translation System at the New Jersey Institute of Technology has highlighted the need for a more concise system for notating the phonetic parameters of movement and position of signs in American Sign Language (ASL). There are five parameters of signs in ASL, HANDSHAPE, LOCATION, ORIENTATION, MOVEMENT, and NONMANUALS, the complexity of which will be explained fully in section 3.1. Of these parameters, only handshape and orientation are defined with sufficient precision to be converted from an existing notation (e.g. Stokoe) to a binary feature system for computer recognition. In attempting to create a similar description for computer identification of movement and location, inadequacies of widely used transcription systems were identified. The objective of this paper is to survey existing notational systems and to define a new notational system to concisely and accurately transcribe movement and location of signs for the purpose of mapping these parameters to inertial positioning data. The notation of nonmanuals has been omitted because it is beyond the scope of this study in terms of what can be measured by the system in question.

1.0 Motivation

Although there are between 600, 000 and 1,000,000 deaf and hearing impaired Americans (Mitchell 2005), the deaf still remain one of the most isolated cultural groups in the United States. This isolation is due in part to the communications barrier between signers and non-signers. The goal of the Americans with Disabilities Act of 1990 is to remove barriers that would prevent the disabled and the deaf from participating in society. It mandates that government services and agencies provide a qualified interpreter if requested by the deaf (*Rights of Deaf*). These services include hospitals, doctors offices, courts, jails, police, fire, school systems, public swimming pools, municipal golf courses, and lottery bureaus; however, due to the shortage of interpreters, interpreters are not always readily available. While the agency must make all efforts to facilitate communication, including paying interpreters fees, it is the responsibility of the deaf person to request an interpreter beforehand; they are not provided automatically. Interpreters may not always be available as part of first-responder teams, such as fire crews, EMTs, or even emergency room staff. The nature of these services generally does not allow time for a qualified interpreter to be found. Additionally, there are many day-to-day tasks, such as banking, shopping, and traveling, which would be facilitated by the presence of an interpreter or even someone who knows a minimal amount of sign. In these situations, the deaf must usually resort to handwritten notes to make themselves understood, but this method can be problematic because of the differences between the structures of ASL and English, and because of the general lower levels of literacy among the deaf.

Machine translation systems, while not a replacement for interpreters in delicate or complicated situations, would at least ease the burden on the interpreting community in situations where precision and accuracy are not critical. They would also enable communication in emergency situations, when no interpreter is available, and would facilitate communications in daily situations that are beneath the importance level that would warrant the expense and encumbrance of an interpreter.

2.0 Machine Translation Systems

Machine translation systems have long been the goal of engineers who work with sign language and of computer scientists who wish to prove their systems. Translating written English, and therefore, through speech recognition software, spoken English, into American Sign Language glosses[1] is a manageable exercise, if not a straightforward one. Computer scientists at the University of Pennsylvania have implemented a two-step process in which they gloss English and synthesize the glosses using fully articulated human model software (Zhao, Kipper, Schuler, Vogler, Badler, & Palmer 2000). Due to

[1] Glosses are the English words that correspond to ASL signs. Glossing is similar to translating, but it omits grammatical information expressed by the order of signs. (Valli & Lucas 2000: 21)

the complexity of sign languages and the volume of data that must be collected and processed in order to accurately gloss ASL, systems for translation of ASL to English have been slower to develop.

2.1 Camera-based Translation Systems

Camera-based systems take a video recording of the signer, then use software to analyze and interpret the data. While these systems have a test run success rate ranging from 52.38% for sentence recognition to 97.8% for a 40-word vocabulary in Contact Sign[2] (Brashear, Starner, Lukowicz, & Junker 2003), the test run environment is markedly different from typical conversational circumstances. First, the experimenters are able to position the camera to provide the fullest view of the signer. Second, the signer is dressed to maximize contrast between the signer and the background. Third, the background is generally a solid color. Lighting is also controlled.

In practice, the signer will be in a cluttered environment, and the line of sight between the camera and the signer may be obstructed. The signer may be wearing wildly patterned clothing, and the lighting may be dim. Additionally, camera-based systems are not inherently mobile. To record a complete view of the signer, the camera must be located a certain distance away. A group at the Georgia Institute of Technology has experimented with hat-mounted cameras (Brashear, Starner, Lukowicz, & Junker 2003); however, positioning and maintaining camera position is difficult. While the hat-mounted camera can capture most of sign space, signs located above the head (e.g. SHOWER) can not be captured. The hat and camera would also present an encumbrance

[2] Contact Sign is a less complex, more regulated version of ASL. It is often used by signers for communication with non-signers.

when signing signs such as GRANDFATHER because GRANDFATHER has a contact point on the forehead.

Figure 1. Example of a hat-mounted camera and the view of sign space recorded by the camera[3]

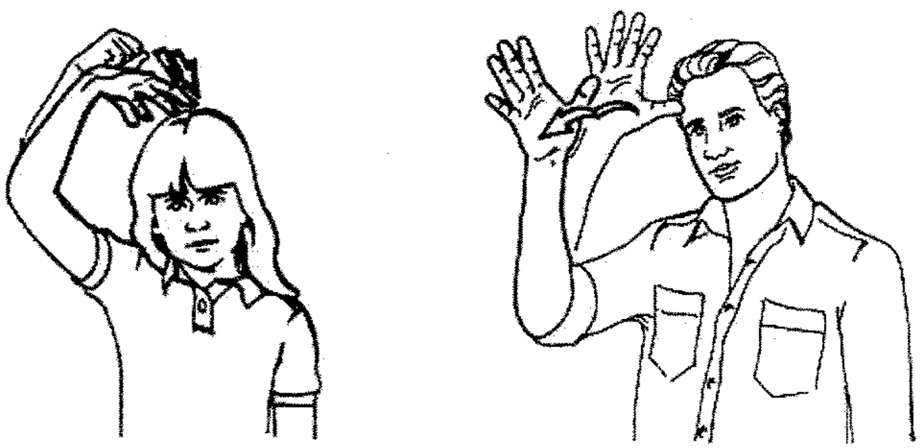

Figure 2. SHOWER and GRANDFATHER

2.2 Magnetic Tracking Based Systems

Magnetic tracking based systems are less dependent on environmental factors than camera systems are, however they have their own limitations. The signer is positioned in front of a base station, which generates several Direct Current magnetic fields. The relative field strengths are detected by sensors worn by the signer. Each sensor

[3] Appendix A lists all sources of figures.

consists of three orthogonal antennas which measure the magnetic fields produced by the base station. Position and orientation are then calculated with respect to the transmitter (Ascension Technology Corporation, 2001). This system has a tracking range of approximately 10 ft (Ascension Technology Corporation, 2000). While this system would work well for a lecturer at a mid-sized to large event, where the signer would remain stationary and the size of the event would justify the work involved with setting up such a system, an event of this size would likely merit an interpreter. This system is obviously not mobile.

2.3 Wearable Translation Systems

Less extensive development has been done in the area of wearable translation systems. The New Jersey Institute of Technology (NJIT) in Newark, NJ has been developing a wearable translation system for use in general situations. In terms of usability such a system must be non-restrictive, simple, and cost-effective. The importance of affordability is self-explanatory; the other requirements are perhaps less obvious. The average person is less likely to regularly use a complicated, restrictive multi-part apparatus, such as a full bodysuit, if he doesn't have to. Even if such a system is more accurate, its lack of appeal to users makes it a less ideal choice. NJIT's proposed system consists of a HANDSHAPE RECOGNIZER, INERTIAL POSITIONING SYSTEM, SIGN INTERPRETATION ALGORITHM, and NATURAL LANGUAGE PROCESSING ALGORITHM.

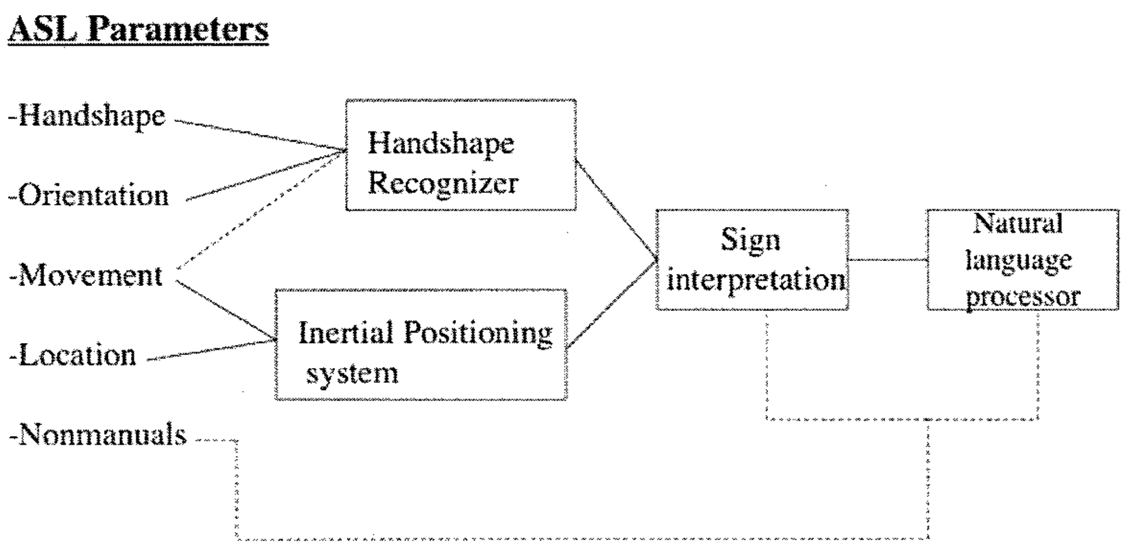

Figure 3. Diagram of NJIT's proposed ASL translation system

To maximize efficiency, classification of parameters should be performed at the level closest to data collection, leaving complex computations such as glossing and natural language processing for the higher level.

2.3.1 Handshape Recognizer

The Handshape Recognizer was designed by an undergraduate senior project team at NJIT under the advisement of Dr. Richard Foulds during the Spring semester of 2005. This team consisted of Computer Engineers Brad Galego, Joseph Lallo, Michelle Paulter, and Rohan Shinde (2005).

The Handshape Recognizer consists of a sensory glove and a 9.8 MHz Motorola 68EC000 microprocessor Single Board Computer (SBC). The system classifies handshape based on binary joint angle bending data from eleven of the cyberglove's 22 sensors (See Appendix B). Based on the data from the metacarpophalangeal sensors, the handshape is classified into one of four subclassifications, then further subclassified based on other data. The handshape recognizer was designed to recognize 25[4] letters of the ASL alphabet; however, classification and recognition of all phonologically significant handshapes could be achieved through different choices of the sensors considered, and by restructuring the handshape classification algorithm. When calibrated for individual users, it has a 100% local accuracy and a 92% global accuracy for the ASL alphabet, where local accuracy refers to success rate in identifying a specific handshape, and global accuracy refers to success in identifying handshapes, overall. Appendices C and D show the handshapes of the manual alphabet and the handshapes most commonly used in ASL. Because the cyberglove has sensors that measure wrist pitch, palm-based orientations can be identified. The cyberglove's effectiveness at determining the orientation of the fingers has not been tested, but the handshape recognizer should be capable of computing finger orientation based on bending of the metacarpophalangeal and interphalangeal joints. So the handshape recognizer can account for handshape and most orientations.

2.3.2 Inertial Positioning System

The inertial positioning system consists of three orthogonally mounted uniaxial cantilever-based accelerometers and a gyroscope mounted on the back of the user's hands. When used in conjunction with the cyberglove, they would presumably be mounted on the cyberglove. The gyroscope measures angular accelerations, which can be used to determine the orientation of the device with respect to gravity. Each

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[4] The 24 static letters of the ASL alphabet are identified by handshape alone. The dynamic letter J has the same handshape as I; however, it can be identified because it has a wrist pitch component that I does not have. Although the dynamic letter Z has a wrist yaw component, it is not significant enough to be measured by the sensors of the cyberglove. Z cannot be identified on the basis of handshape because it is identical to G.

accelerometer consists of a microcantilever which oscillates at its mechanical resonance frequency. Changes in acceleration produced by movement result in changes in resonance frequency. Since maximum reflected power occurs at resonance, these changes are measured by a circuit that performs a frequency sweep and measures reflected power to determine frequency shift, which correlates to acceleration. The acceleration data is then double-integrated to find the displacement of the hand in each direction of motion. Integration naturally introduces significant drift error over time; however, we believe that it can be reduced through periodic calibrations. The merits of both numerical and symbolic methods of integration have been discussed with respect to this device. Numerical methods are microcontroller-friendly, but they require good filtering and have more stringent requirements for sampling rates. Data from modeling methods are easy to downsample, but these methods are complex, and require curve-fitting. Since the acceleration data from each accelerometer are unidimensional, the data from all three accelerometers are then combined to construct an accurate model of the hand's movement in three-dimensional space. These measurements determine both movement and position for the hands.

2.3.3 Nonmanuals

Although some camera systems are able to record nonmanuals (Goldenstein, Vogler, & Metaxas 2004), there is no set of wearable sensors to measure facial movement since these sensors must be both unobtrusive and comfortable. Since there is no system in place to handle nonmanuals, they have been omitted from the discussion.

2.3.4 Sign Interpretation

After initial classification based on sensor data, the final system will use handshape, orientation, location, and movement parameters to gloss the signs.

2.3.5 Natural Language Processing

Natural language processing will be performed on the glosses to make the syntax similar to that of English. Improper glossing can render an utterance unintelligible. This is a crucial step because, if not done properly, it could reinforce the misconceptions that ASL is not a natural language and that deaf people are not as intelligent as hearing people.

3.0 American Sign Language

American Sign Language is a structured visual-spatial communication system; it is a natural language, and distinct from other sign languages. It is also not signed English, which uses a signed vocabulary with English syntax. As in spoken languages, a signer can display emotions (through facial expressions), shout (by moving outside of the well-defined sign space), and swear. It should be noted that signs are not the same as gestures.

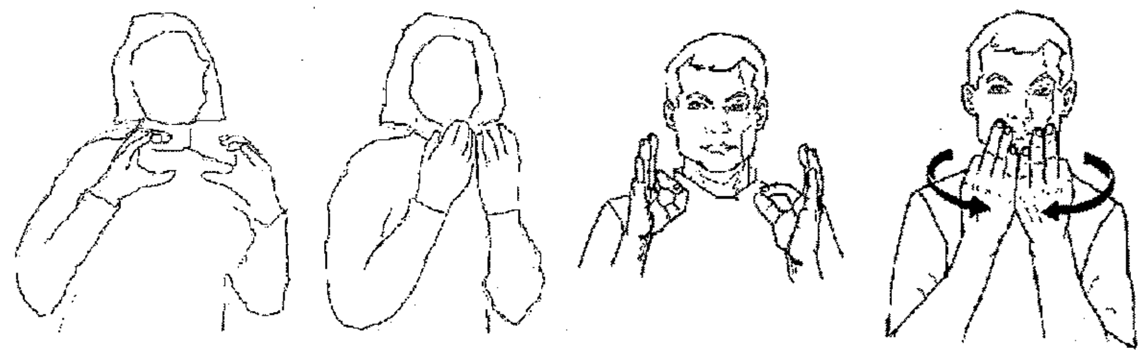
Instead of translating, I have followed the convention of glossing signs in capital letters.

3.1 Five Parameters

There are five basic parts to every sign in American Sign Language. These parameters are handshape, orientation, location, movement, and nonmanuals. Handshape refers to the configuration of the hand. In a fully descriptive phonetic system, the articulation of the palm and all fingers would be specified. See Appendix C for the common list of handshapes in ASL. Orientation is a complex parameter that refers to the direction the palm and fingers are facing with respect to the signer. Location refers to the position of the hands in sign space. Sign space has been divided into a varying number of discrete regions, depending on the transcription system. Movement describes the path, end points, and quality of path taken to change locations in sign space. Qualities include the shape, direction, relative speed, and magnitude (in cases where the final position is not specified) of the path. Some notation systems also use movement to describe changes in handshape and orientation. Nonmanuals refer primarily to phonologically significant facial movements. These include, but are not limited to, raised eyebrows, puffed cheeks, protruding lips, tongue positioning, and head shaking. The importance of these parameters can be demonstrated through minimal pairs, or signs that differ only in one parameter.

Table 1. Minimal pairs for Handshape

Gloss	**Handshape**	**Orientation**	**Location**	**Movement**	**Nonmanual**
CLASS	**C**	Begins palms out, ends palms in	Chest height, in front of the body OR Center of null space	Both hands follow a symmetric path, reflecting across the midsagittal plane, tracing a horizontal semi-circle that begins in front of the body and ends when the outside edge of the hands contact at the distant point of the circle	None
FAMILY	**F**	Same	Same	Same	Same



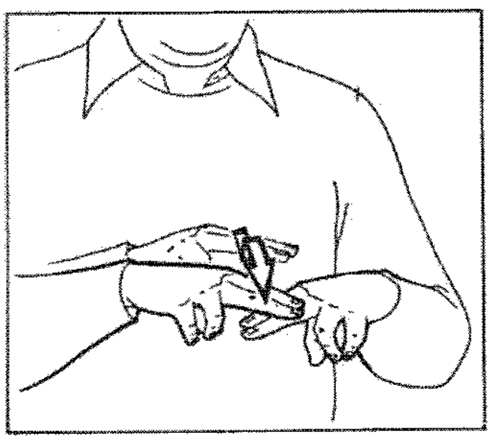
CLASS FAMILY

Figure 4. CLASS and FAMILY

Table 2. Minimal Pairs for Orientation

Gloss	Handshape	Orientation	Location	Movement	Nonmanual
NAME	H	**Palms in**	Neutral	Extended fingers of dominant hand contact extended fingers of nondominant hand twice	None
CHAIR	Same	**Palms down**	Same	Same*	Same

* When signing NAME, the lower side of the bottom finger of the top hand contacts the upper side of the top finger of the bottom hand. The contact point for CHAIR is the underside of the fingers of the top hand with the topside of the fingers of the bottom hand. This difference is a result of the orientation of the hands.



NAME

CHAIR

Figure 5. CHAIR and NAME

Table 3. Minimal Pairs for Location

Gloss	Handshape	Orientation	Location	Movement	Nonmanual
SUMMER	1 Handshape, transitioning to X handshape	Palm down	**Forehead**	Horizontal movement across the width of the face	None
DRY	Same	Same	**Chin**	Same	Same

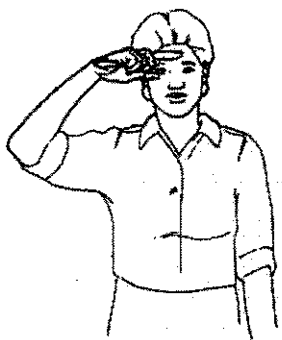
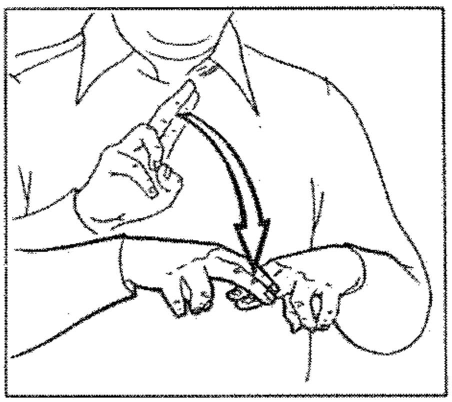


Figure 6. SUMMER and DRY

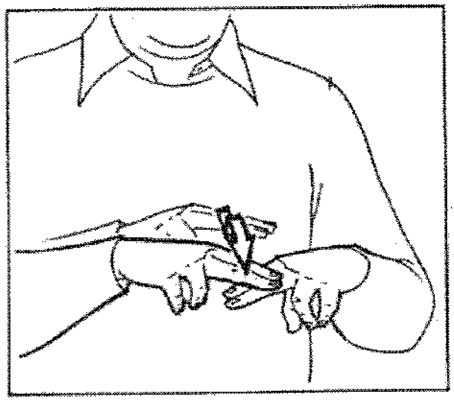
Table 4. Minimal Pairs for Movement

Gloss	Handshape	Orientation	Location	Movement	Nonmanual
SIT	H	Palms down	Neutral	Extended fingers of dominant hand contact extended fingers of nondominant hand **once.** This movement is **slow** in comparison to CHAIR	None
CHAIR	Same	Same	Same	Extended fingers of dominant hand contact extended fingers of nondominant hand **twice.** This	Same

				movement is **quicker** than the movement in CHAIR	



SIT



CHAIR

Figure 7. SIT and CHAIR

Table 5. Minimal Pairs for Nonmanuals

Gloss	Handshape	Orientation	Location	Movement	Nonmanual
BALL	All fingers open, but held lax	Palms in	Neutral	Fingers come apart, then contact, twice	**None**
BALLOON	Same	Same	Same	Same	**Puffed cheeks**

Figure 8. BALL

3.2 Linguistic Descriptions

Two of the most widely used descriptive systems of the structure of signs are the Stokoe system and the system devised by Liddell and Johnson.

3.2.1 The Stokoe System

William Stokoe was the first person to describe signs as a series of parts, which he called CHEREMES. He labeled them TABULA, DESIGNATOR, and SIGNATION, corresponding to location, handshape, and movement. Orientation information was built into the signation cheremes. Stokoe specified the order of the parameters as tabula, designator, signation. (Valli 2000) See Appendix E for the complete Stokoe chart.

Stokoe's system is generally regarded by linguists to be incomplete. Transcriptions do not specify final locations. Although final locations can be inferred from the movements, they should be specified since final location can have semantic relevance. Signs which indicate degree, such as LONG, VERY LONG, and TREMENDOUSLY LONG, require the transcription of a final location in order to capture their full meaning.

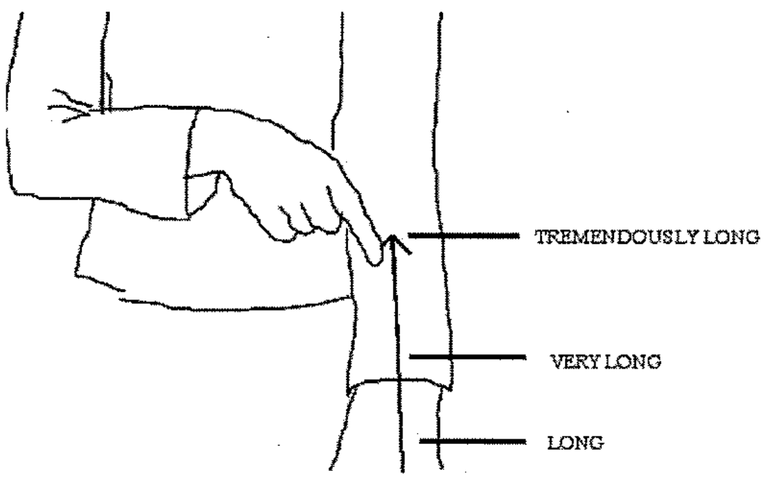


Figure 9. The degree of length is shown by the final location for the signs LONG, VERY LONG, and TREMENDOUSLY LONG

In contrast, both movement and final handshape are specified when the movement results in a change in handshape. Both of these reasons contribute to the Stokoe system's unsuitability for a computational representation of movements. While Stokoe specifies straight paths of movement in all directions, curved movement paths, such as would be found in CLASS or FAMILY, or angled paths, such as in PRINCESS, would have to be specified through a combination of signations.

Figure 10. PRINCESS

$[]\ K^{>V}$

Figure 11. Stokoe Representation of PRINCESS

The linearity of Stokoe's notation may at first seem to map nicely to a triaxial accelerometer system because each direction of movement in the Stokoe system corresponds to a direction of motion for an accelerometer, and because complex movements must be broken down in the notation; however, in order to remove the component of the acceleration due to gravity, the axes of the accelerometer must be mapped to a standard Cartesian coordinate system. Since the signer will usually not have his hands rotated so that the accelerometers are oriented along Stokoe's paths of movement, additional calculations would be necessary to correct for the misalignment. Such corrections will be necessary for any notational system.

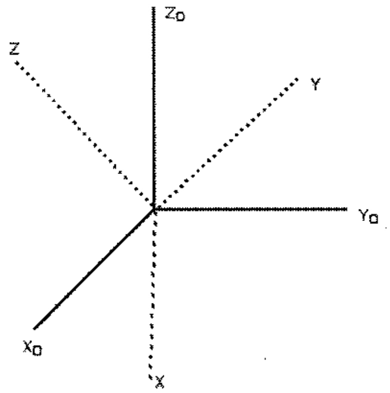


Figure 12. The solid axes, Xo, Yo, and Zo represent the Cartesian coordinate system, or the orientation of the hand with respect to gravity, where Zo is opposite the direction of gravity. The dotted axes represent the orientation of the sensors on the hand when the hand is in one possible position.

While designing the inertial positioning system, Brad Galego and I originally looked at using the Stokoe system for location. Stokoe defined twelve regions: null or neutral space, the face/whole head, forehead/upper face, mid-face, lower face, side-face, neck, trunk, upper arm, forearm, wrist in supinated position, and wrist in pronated position.

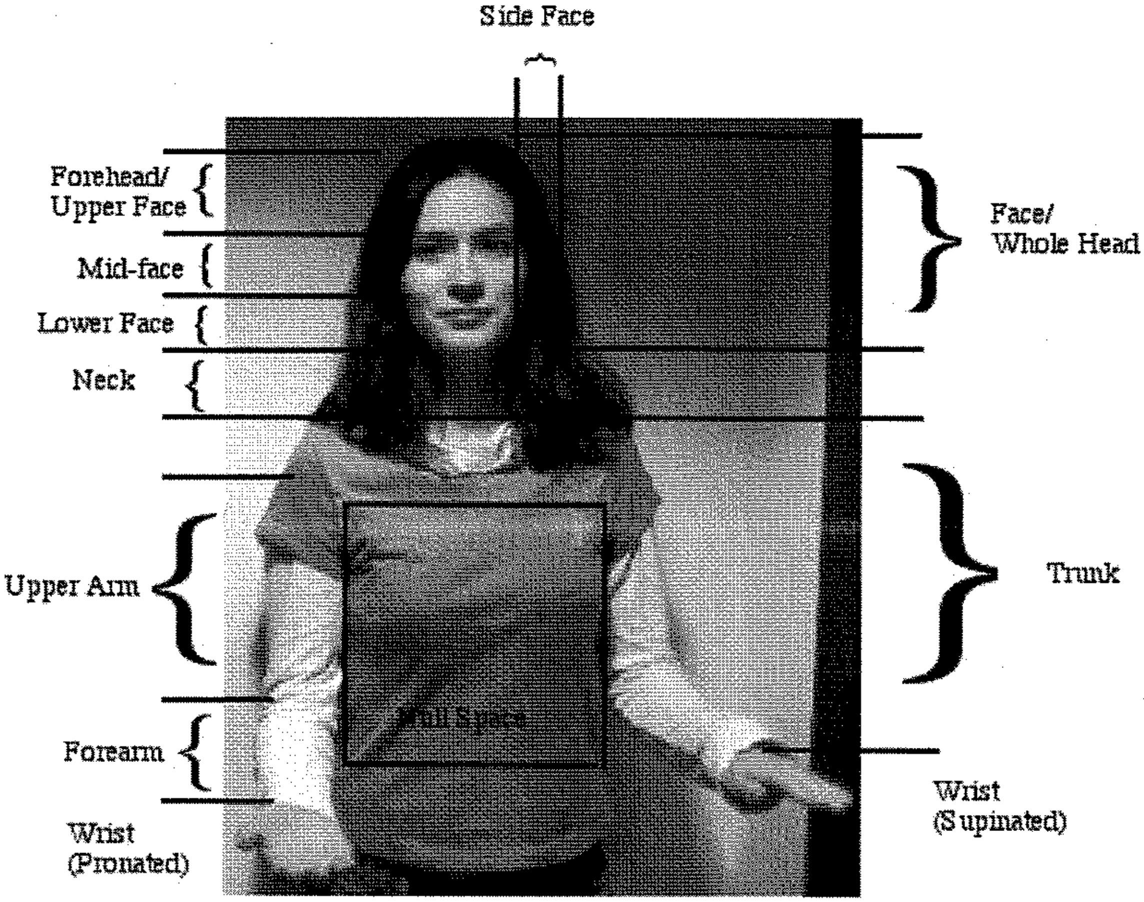


Figure 13. Stokoe's regions of sign space

We removed the region referring to the whole head because the region was divided into four subclassifications that would be identified by the system. If the other parameters of the sign did not match the parameters of a sign in the specific region, the location would then default to the full face. We conflated the two wrist positions because supination and pronation can be determined by a combination of the gyroscope and the handshape recognizer. We also subdivided null space into four regions based on lateral position and height, for a total of fourteen discrete regions of sign space.

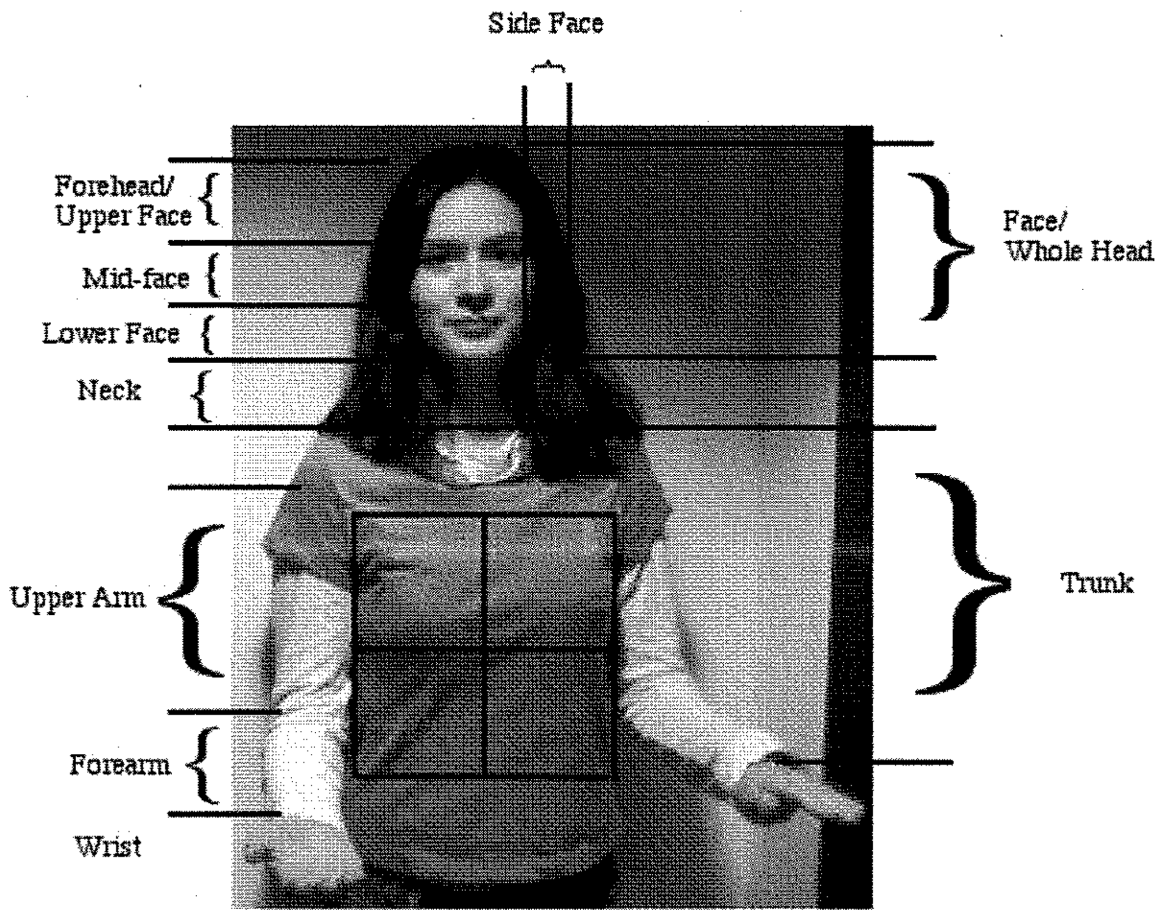


Figure 14. Modified Stokoe regions of sign space

One option that would make the Stokoe System adaptable for use with the inertial positioning system would be to expand the movement and orientation notations to include more phonological information, and to rework the ways in which movement paths are calculated by the acquisition system; however, such a recalculation may prove computationally complex, and therefore may not be the most efficient method.

3.2.2 The Movement-Hold System

Scott Liddell and Robert Johnson developed the Movement-Hold model of sign structure. They claimed that signs were composed of sequences of MOVEMENT segments and HOLD segments. A hold is defined as any period of time during which handshape, orientation, location, and nonmanuals are held constant. A movement is defined as a transition between holds, during which at least one of the four parameters changes. Initial and final articulatory features are defined for movement segments; only one set of articulatory features is required for holds, since holds are static.

Because not all movement paths in ASL are straight, Liddell and Johnson specify CONTOURS OF MOVEMENT. These paths are STRAIGHT, SEVEN, and ROUND. The straight path is a direct movement. The seven path is an indirect path that angles sharply at the middle point. The round path maps to CIRCLES and ARCS, the only difference being that circles begin and end at the same location.

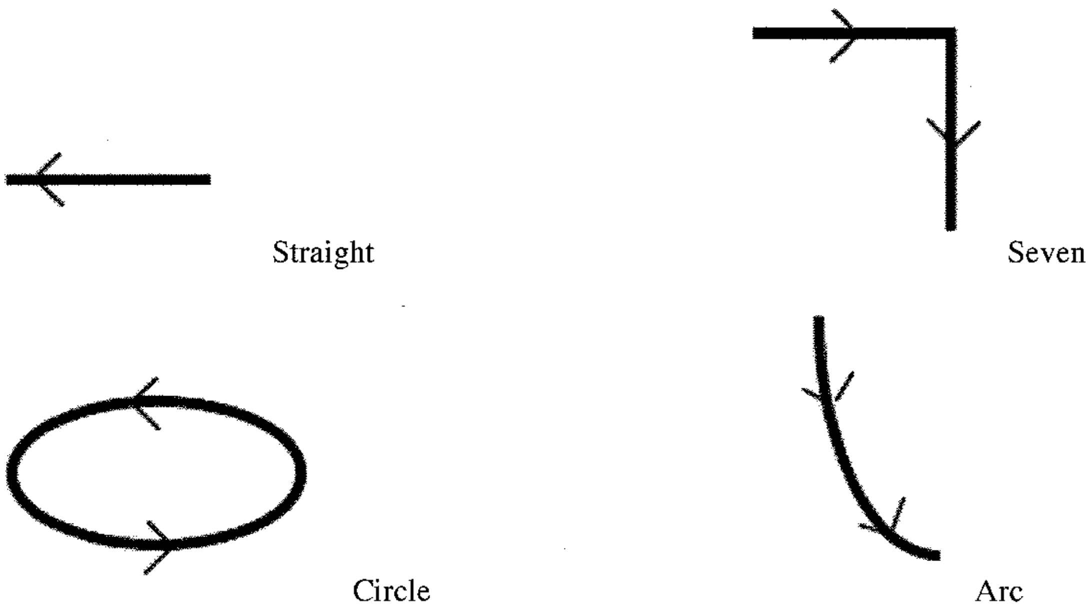
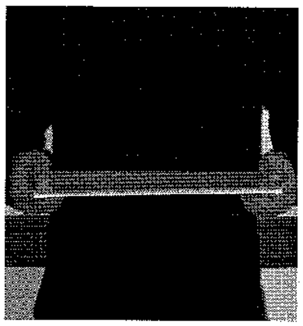


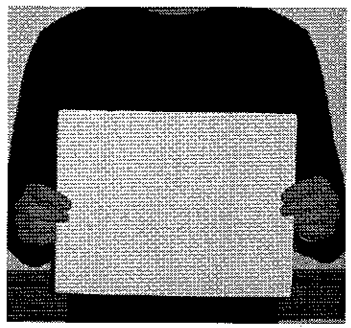
Figure 15. Contours of Movement

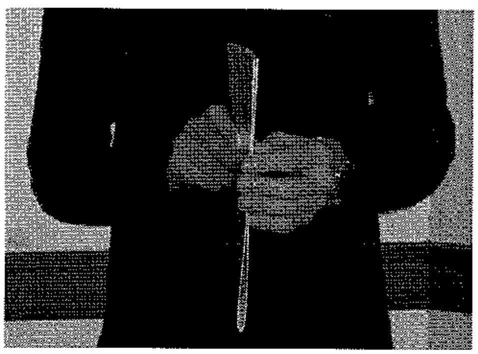
When a contour of movement is defined, a corresponding Contour Plane must be defined to specify the plane in which the hand is traveling. Lidell and Johnson define five planes: horizontal, vertical, surface, midline, and oblique.

Table 6. Contour Planes

Plane	**Reference surface**
Horizontal	Parallel to floor
Vertical	Parallel to front of torso
Surface	Parallel to surface of the body at a specified location
Midline	Perpendicular to surface plane of the torso at midline of body
Oblique	Intersects horizontal plane at an acute angle


Horizontal Plane


Vertical Plane


Midline Plane

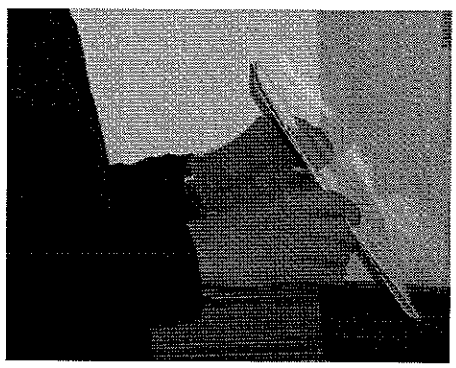
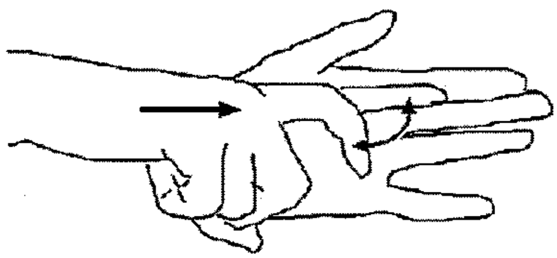

Oblique Plane

Figure 16. Contour Planes. The surface plane has been omitted because it is defined with respect to individual locations of the body.

Liddell and Johnson refer to dynamics as QUALITY FEATURES. The ones they define are prolonged, shortened, accelerating, tense, reduced path, enlarged path, and contacting. The local movements defined are: wiggling (e.g. COLOR), hooking (e.g. WORM), flattening (e.g. GO OUT), twisting (e.g. WHERE), nodding (YES), releasing (WHAT TO DO), rubbing (e.g. MONEY), and circling (e.g. BASEMENT) (Liddell & Johnson 1989: 283).

A



B

C

D

Figure 17. Examples of internal movement. A: COLOR, B: WORM, C: GO OUT, D: WHERE, E: YES, F:, WHAT TO DO, G: MONEY, H: BASEMENT.

While the Movement-Hold system implies wrist rotation and direction of movement through the orientation and location parameters specified in the hold segments adjacent to a movement segment, Christian Vogler and Dimitri Metaxas (1999) argued that specifying both would aid in their recognition system. They also specified noncontacting locations as proximal, medial, distal, or extended with respect to the body.

Such additions to the Movement-Hold system indicate that it is not ideal, even for systems with the complexity to handle articulatory bundles.

The Hold-Movement model has been the preferred model for continuous ASL recognition, using HIDDEN MARKOV MODELS (HMMs). HMMs are an automated decision-making algorithm which makes predictions probabilistically. By comparing the data in question with a previously stored body of signs called a training set, they are able to divide a data stream into constituent signs. The sequential nature of the Movement-Hold model matches with the sequential nature of HMMs; however, due to the sheer volume of combinatorial possibilities in ASL, it is impractical to train HMMs for anything but small vocabularies. To make translation of ASL tractable, Vogler, Sun, and Metaxas (2000) divided the articulatory bundles of the hold segments of Liddell and Johnson's model into CHANNELS, each channel equivalent to one of the remaining four parameters of a sign, and each phoneme was given its own HMM. The set of HMMs for each parameter is independent from the sets for the other parameters. These new HMMs are run in parallel, as Parallel Hidden Markov Models (PaHMMs), and the resulting probabilities are combined to determine the most likely sign.

Note should be made that the PaHMM framework is used for interpretation of parameters, not for interpretation of sensor data. Vogler, Sun, and Metaxas use the Ascension Technologies MotionStar™ 3D tracking system in conjunction with their own camera-based tracking system for data collection, but they do not elaborate on their methods of classifying parameters. NJIT's data collection system has the advantages of being both wearable, and therefore portable, and less expensive.

4.0 Transcription Systems

The goal of any transcription system is to accurately represent the details of an utterance in a usable format. This section focuses primarily on notations for movements and locations that are compatible with the inertial positioning system, since handshape and orientation can be adequately represented for use with the handshape recognizer by other notation systems. The suitability of these transcription systems for use with the NJIT data acquisition system is outlined, with the goal of selecting the best elements for use in a new notational system.

4.1 HamNoSys

The Hamburg Sign Language Notation System (HamNoSys) was developed as a phonetic transcription system for all sign languages. Essentially, it is the sign language equivalent of the International Phonetic Alphabet.

HamNoSys has about 200 characters which are used to indicate initial configuration, actions, and symmetry operators of the hands for a given sign. Handshape is given by a combination of basic form, thumb and finger opening, bending, and closing, and specific finger articulation and points of contact. Orientation is defined by orientation of the fingers and the palm, from a set of 18 major orientations, which can be combined to form 8 distinct minor orientations, for the fingers and 16 orientations for the palm.

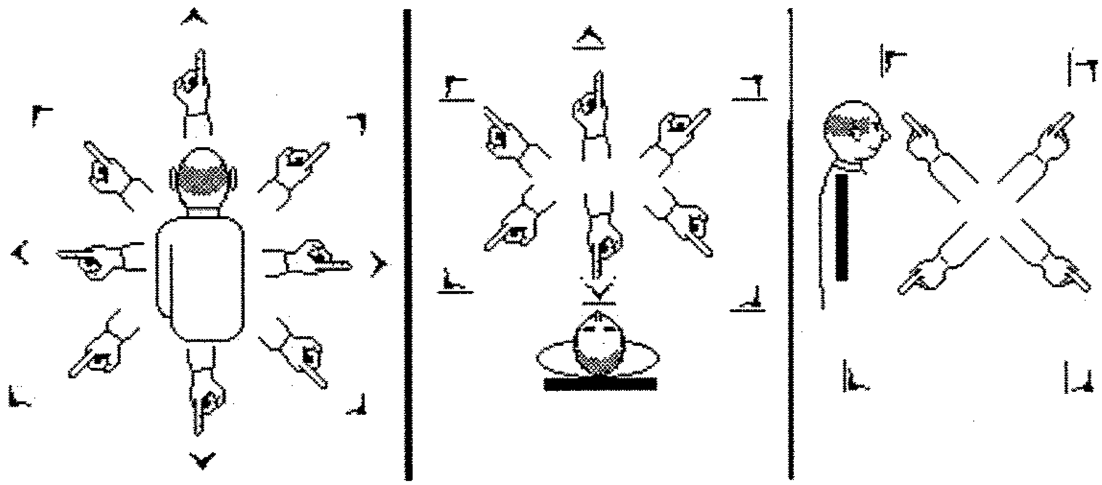


Figure 18. Major finger orientations

These orientations are far more descriptive than are necessary for classification of signs.

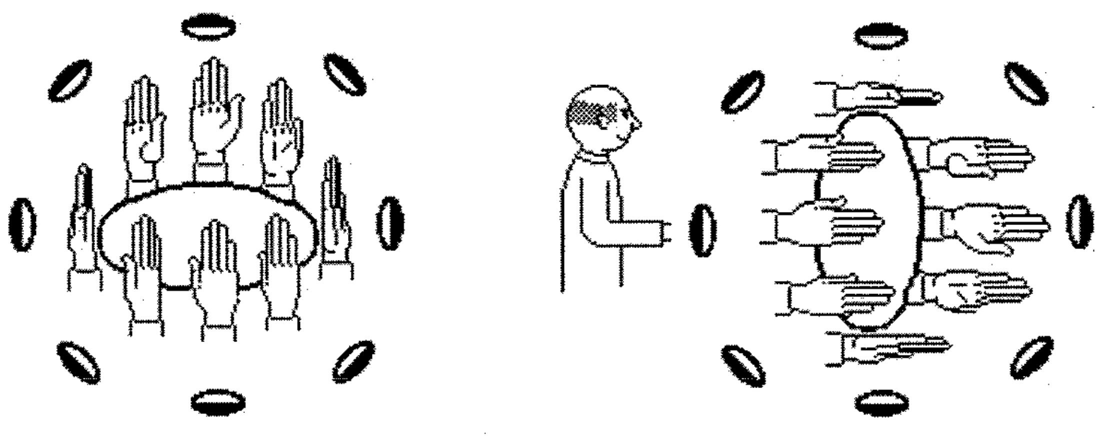


Figure 19. Palm orientations

Location can be represented in terms of location on the body and relative distance from the body.

HamNoSys defines movements as either absolute or relative. Absolute movements have set initial and final locations, as well as a direction and size, whereas relative movements do not have a specified final location. Movement paths can be straight, curved, wavy or zig-zag, or circular. The directions of straight line movement are similar to the direction of finger orientations, and can be likewise be combined to express intermediate directions.

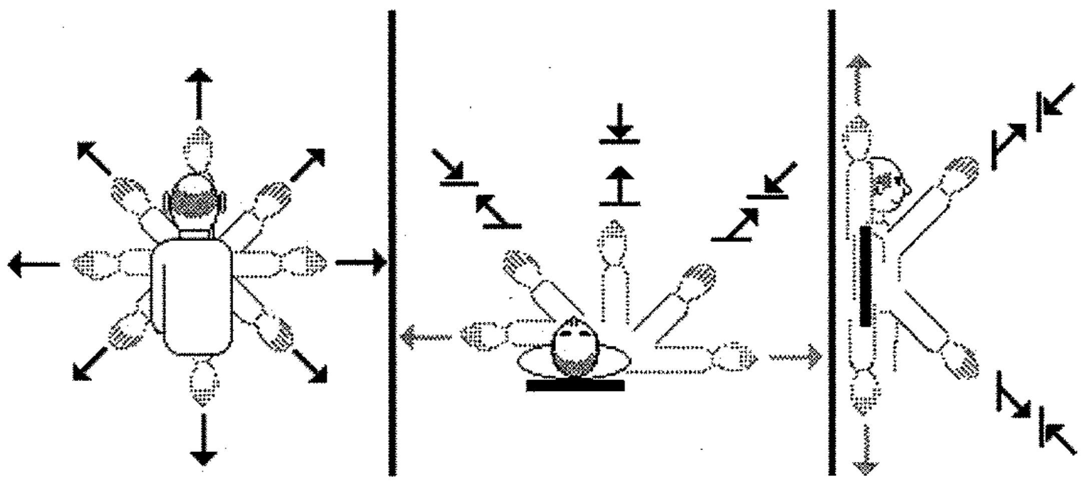


Figure 20. Directions of straight line movement

Curved movements are indicated with the linear direction of movement and a curve indicating the direction of the curved movement. Likewise, wavy movements are represented with a wave symbol and a linear direction. The direction of travel is always written before the direction of the curve. As for orientation and straight paths, the curves can be combined to indicate intermediate paths.

Table 7. Curves and wavy movements

Direction	↖ ↑ ↗ ↙ ↓ ↘ ↖ ↙ ↘ ↗	↑ ↓	← ↖ ↗ → ↘ ↙
Curve (	Curve to the left while moving in the direction indicated	Left	Toward body
Curve)	Curve to the right while moving in the direction indicated	Right	Away from body
Curve ∩	Curve starts from the bottom and moves up, moving in the direction indicated	Away from body	Curves up
Curve ∪	Curve starts from the top and moves down, moving in the direction indicated	Toward body	Curves down
Wavy ∿	Hand oscillates in the vertical direction while overall travel is in the direction indicated by the arrow	Hand moves towards and away from the body, parallel to the floor, while the overall direction of travel is in the vertical direction	Hand oscillates in the vertical direction while overall travel is in the direction indicated by the arrow
Wavy ∿	Hand oscillates from left to right while the overall travel is in the direction indicated by the arrow	Hand oscillates from left to right while the overall travel is in the direction indicated by the arrow	Hand oscillates towards and away from the body while the overall travel is in the direction indicated by the arrow
Zig-zag ⩘	Hand oscillates in the vertical direction while overall travel is in the direction indicated by the arrow	Hand moves towards and away from the body, parallel to the floor, while the overall direction of travel is in the vertical direction	Hand oscillates in the vertical direction while overall travel is in the direction indicated by the arrow
Zig-zag ⩘	Hand oscillates from left to right while the	Hand oscillates from left to right	Hand oscillates towards and away from the body

	overall travel is in the direction indicated by the arrow	while the overall travel is in the direction indicated by the arrow	while the overall travel is in the direction indicated by the arrow

Circular movements use 18 distinct characters to indicate starting point, spatial orientation and direction of motion, as well as magnitude and fraction of the path completed. Elliptical movements can also be indicated. The direction of rotation is written first, and is immediately followed by either the initial and final positions for either a circular or elliptical path. Paths of more than a full rotation are indicated by the insertion of a circle with crosshairs between the symbols for initial and final positions.

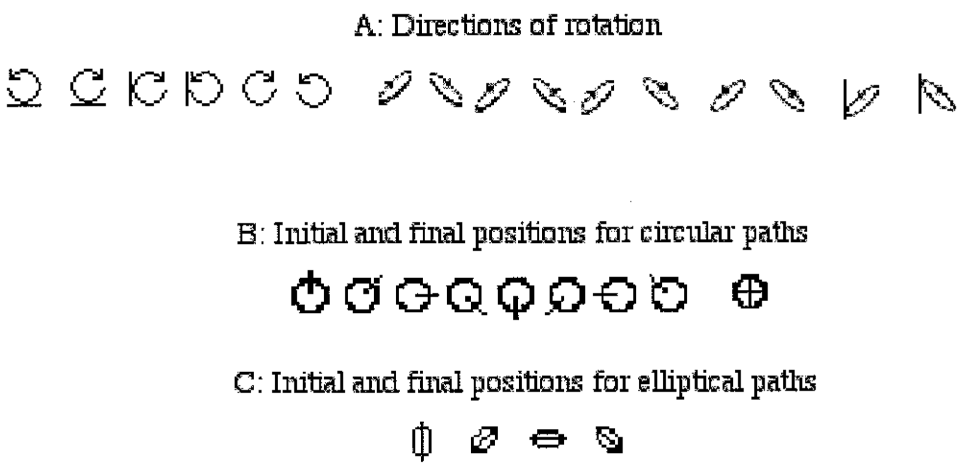


Figure 21. Symbols for circular and elliptical movements.

From a movement path-based perspective, it makes sense to conflate circular and curved movements because curves are merely incomplete circular paths. As such, a curve could be written as some fraction of a circle. Since the position data would be virtually identical for the two movements, it essential not to have multiple ways to notate the same thing.

Internal movement and changes of handshape are also represented as movements. Section 5.2.1 explains why this representation is not ideal for use with the inertial positioning system.

Symbols identify whether a movement is repeated once or frequently. Repetition in the opposite direction from the original direction of travel can also be shown.

Table 8. Repetition symbols

Symbol	Type of Repetition
+	One time
⧺	Frequently
+›	One time, frequently
⧺›	Multiple times, frequently
ˈ+	In the opposite direction

If a two-handed sign is symmetric, the sign reflected parameters of the sign are isolated with brackets, and the condition of symmetry is indicated immediately before the brackets. The hands are assumed to have the same lateral orientation, unless otherwise specified.

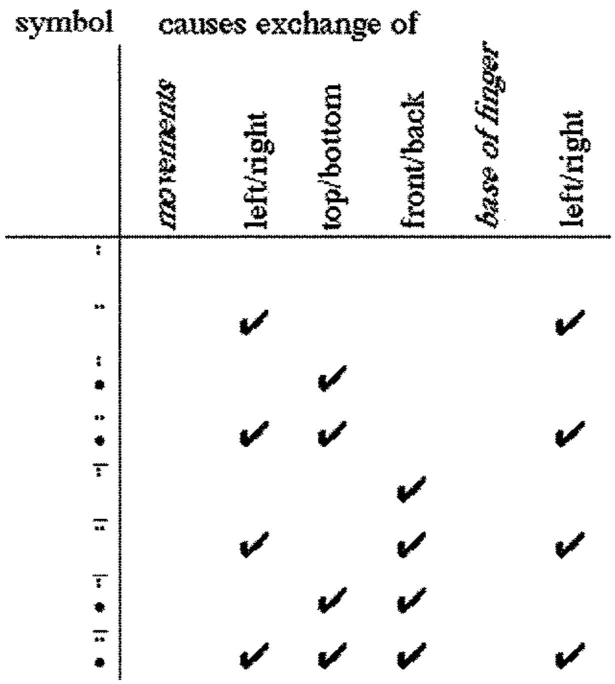


Figure 22. Symmetries

The fact that there are so many symbols for movement, most of which can be combined to illustrate more complex movements, makes HamNoSys difficult to read, and has the potential to introduce inaccuracies in transcription because the user may not be certain which description best characterizes the movement. The iconicity of the majority of the symbols is an asset of HamNoSys, but not all movement paths defined in this notation map exclusively to one phonological path. This multiplicity is less efficient than a smaller set of allowed movement paths, each of which maps to only one or two phonological paths, for characterizing movements for identification by the inertial positioning system.

4.2 Labanotation

LABANOTATION, or LABAN MOVEMENT WRITING is a movement notation system capable of representing all human movement, no matter how complex. It is most commonly used for dance, however Laban has been used to transcribe both Plains Indian Sign Talk (PST) and Auslan, an Australian sign language.

4.2.1 Basics

Laban is always written from the point of view of the dancer. The staff consists of columns representing body articulators around a center line.

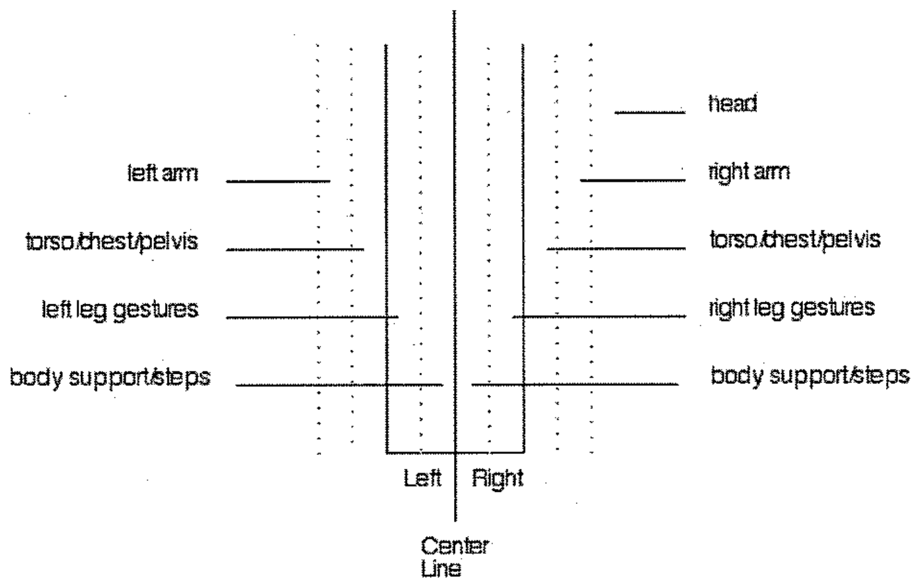


Figure 23. Basic Laban Staff

Movement of individual joints or limbs is depicted using the slightly iconic symbols shown in Figure 24.

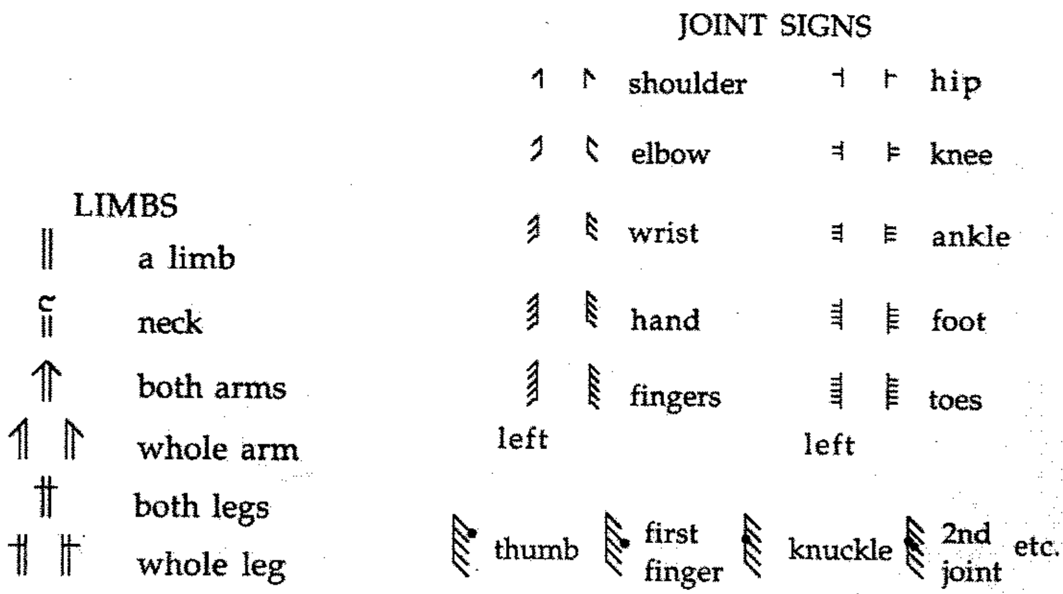


Figure 24. Laban symbols for limbs and joints

Area of the body is also indicated with signs.

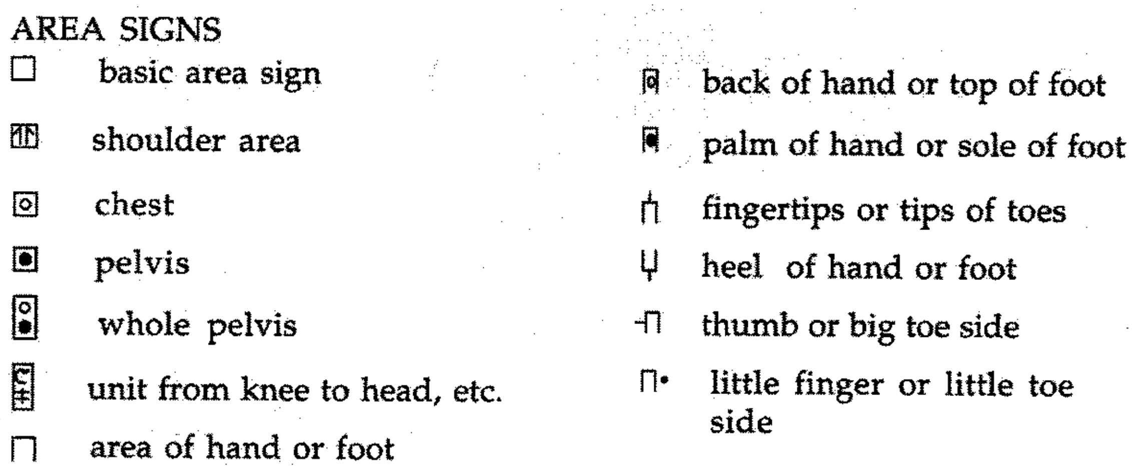


Figure 25. Area of the body symbols

Movement through or location in space is indicated through rectangle-based symbols representing horizontal direction, with shading indicating vertical movement.

This scheme establishes a three-dimensional set of axes with the origin located at the center of the whole body or a joint, depending on which is indicated by signs or placement on the staff.

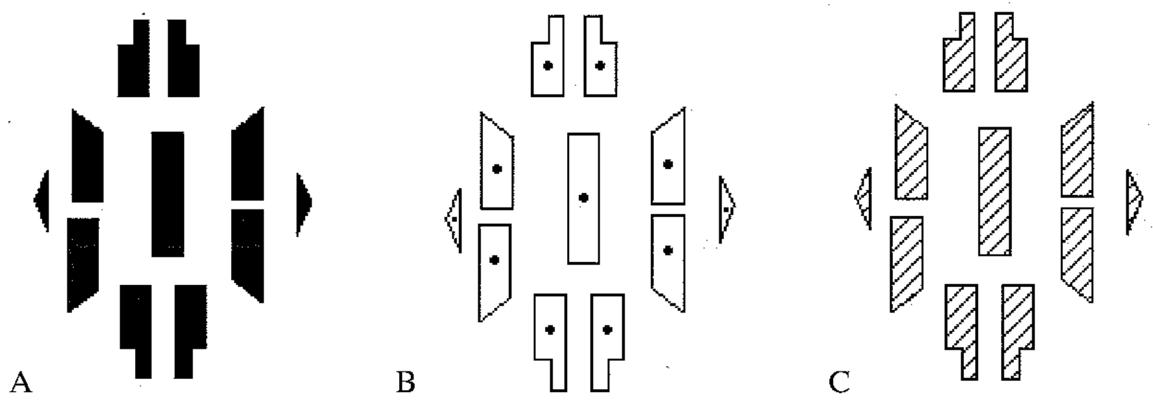


Figure 26. Directions of movement at the low (A), mid (B), and high (C) levels.

There are also symbols for minor directions of movement, directions that fall between the thirty-three directions indicated above. These are often used to indicate spatial relationships with other articulators or parts of the body.

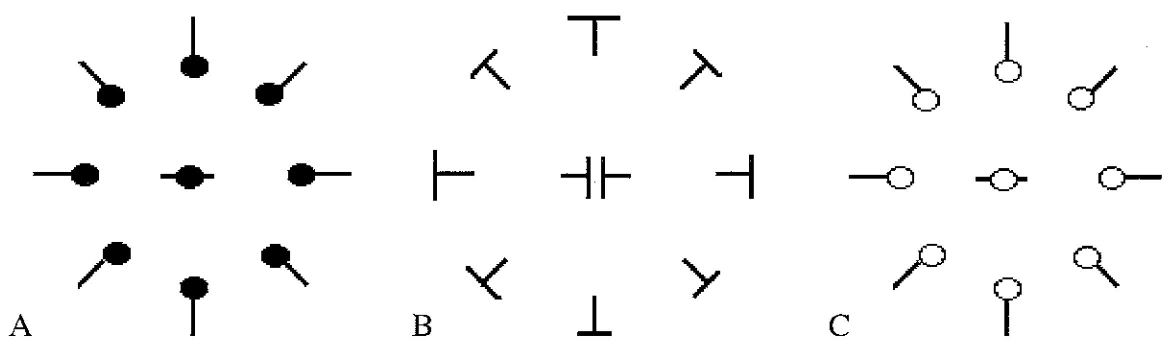


Figure 27. Minor direction symbols at the low (A), mid (B), and high (C) levels

Additional movement paths account for curved motion.

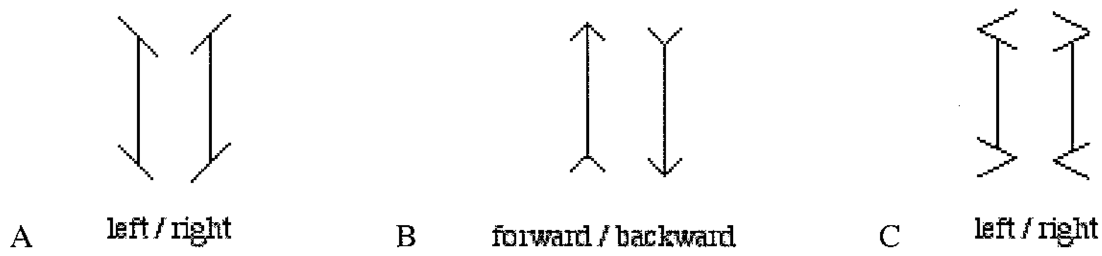


Figure 28. Symbols for curved paths in the horizontal (A), sagittal (B), and lateral (C) planes

These symbols make it possible to transcribe the movements of signs such as CLASS and CHOMSKY in one step, rather than multiple steps, as in the Stokoe System.

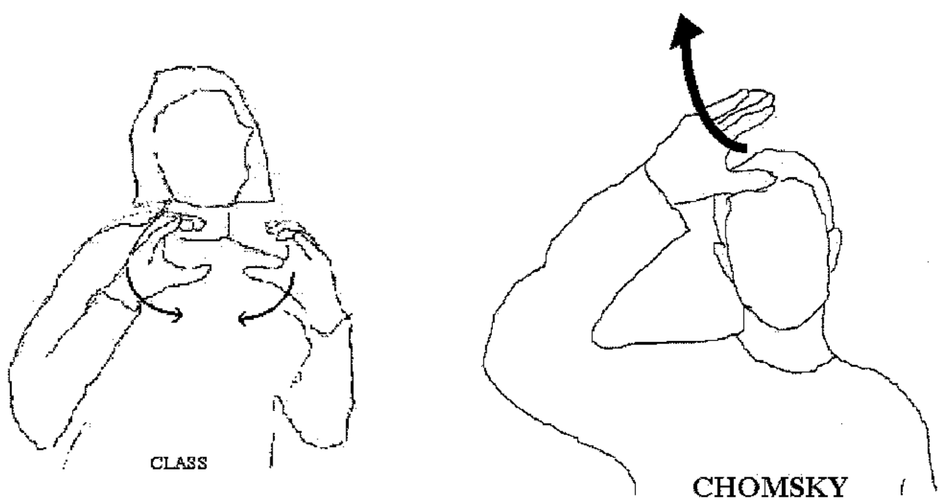


Figure 29. CLASS and CHOMSKY

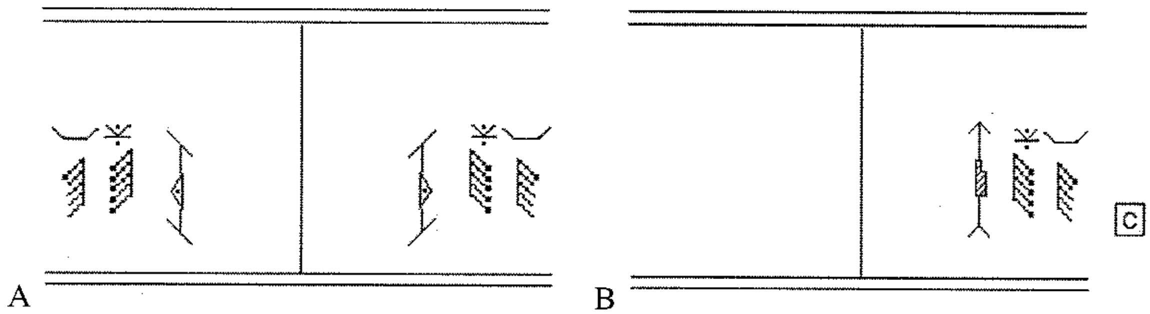


Figure 30. Transcription of CLASS (A) and CHOMSKY (B) in labanotation. Both signs are written on Farnell's modified staff rather than the traditional laban staff to avoid extraneous body details.

Relationships that are not cardinally directional can also be indicated, as well as relationships between parts of the body such as contact, proximity, grasping, penetrating, sliding while in contact, and passing.

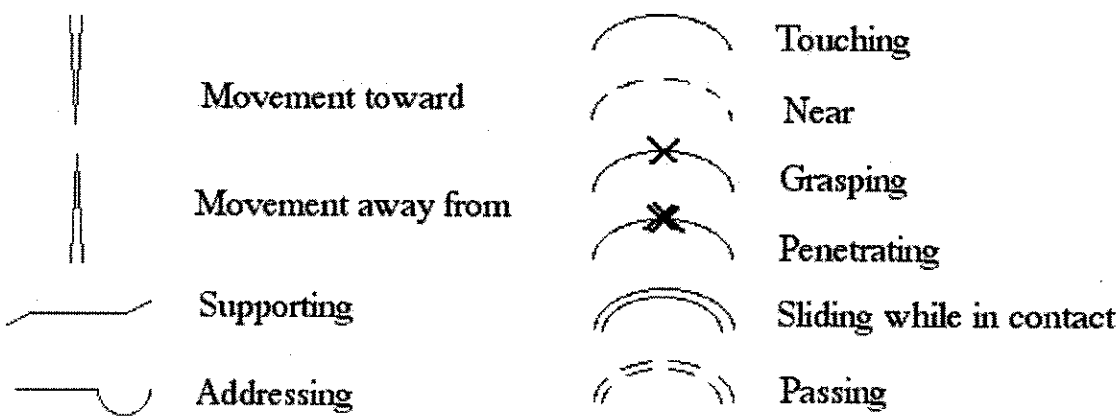


Figure 31. Movement relationships with respect to other body parts

Extension, contraction, and degrees of both, as well as physical dynamics such as acceleration, tension, and initial and final locations can be indicated. Repetition and symmetry are also notatable.

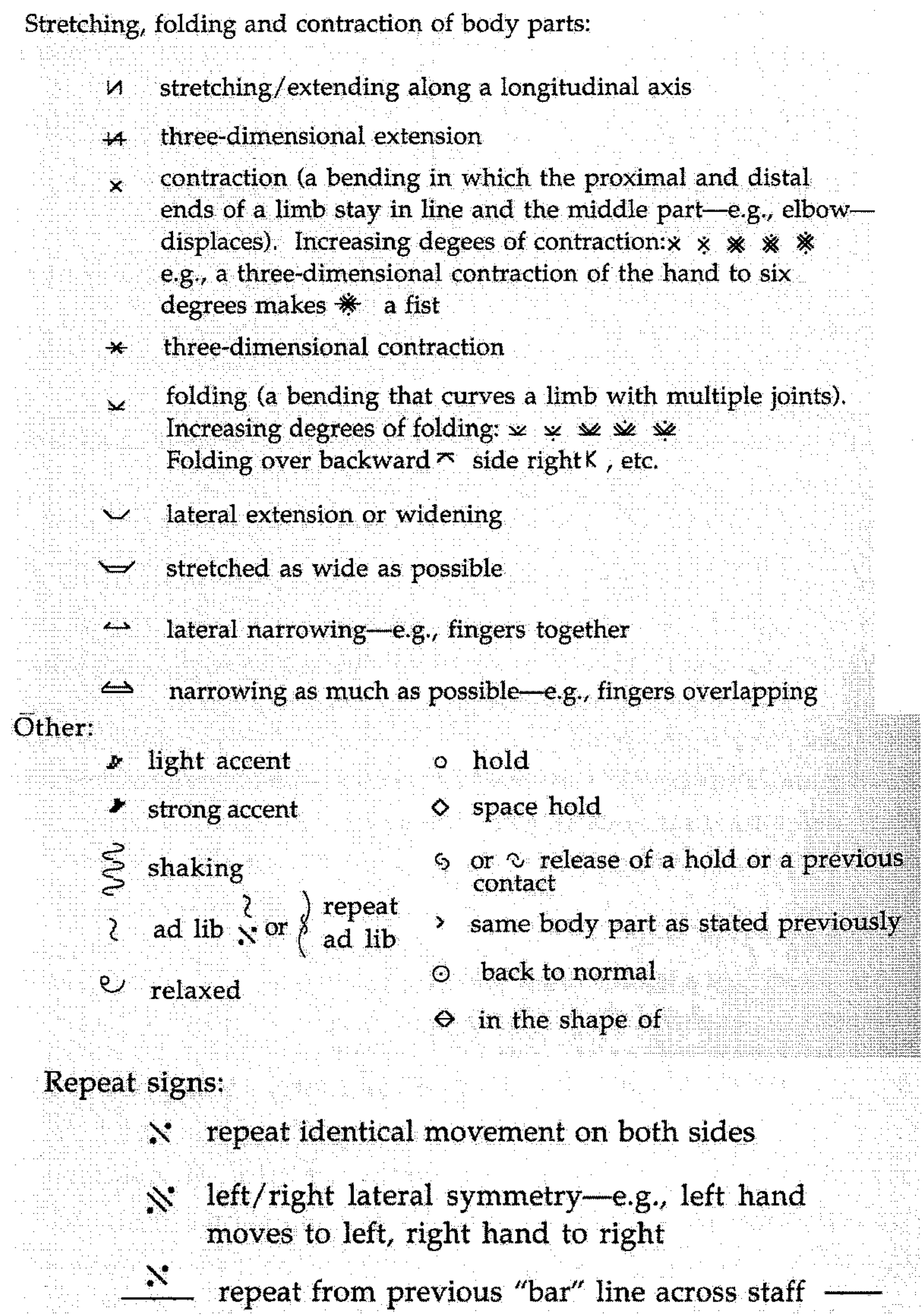


Figure 32. Extension and contraction, dynamics, repetition/symmetry symbols

Labanotation is read from bottom to top, with the vertical axis acting as a time axis. Absolute or relative timing can be specified; however, for most dance transcriptions, the time axis is divided in units of measures, or musical phrases. If no time scale is specified, symbols are written as the standard length, and relative durations of movements are indicated by the length of the drawn symbol.

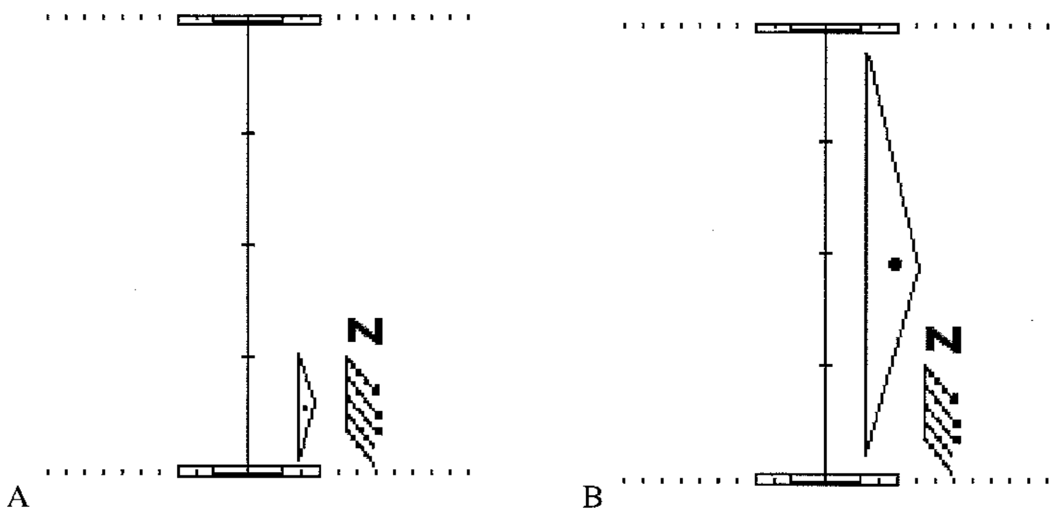


Figure 33. Laban transcription of CAR-DRIVE-BY, showing relative durations of tmovements on a generic time scale. A: CAR-DRIVE-BY QUICKLY. B: CAR-DRIVE-BY SLOWLY.

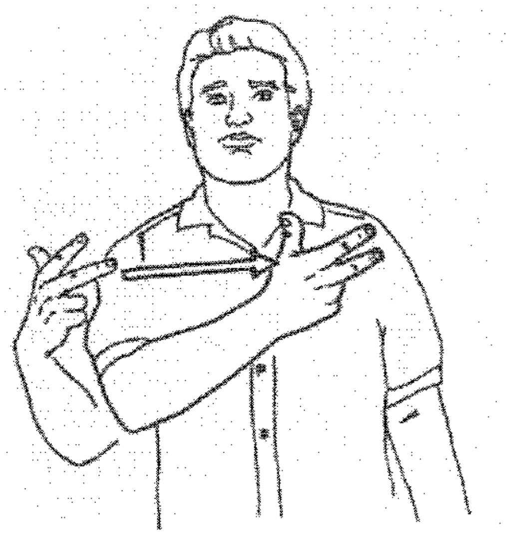


Figure 34. CAR-DRIVE-BY

No mention is made of notating nonmanuals. This oversight may be because facial expressions are not often prescribed in dance choreography.

4.2.2 Use of Laban to Notate Plains Indian Sign Talk

For her research on the use of sign language in Native American storytelling, Brenda Farnell used a modified version of labanotation to transcribe the signed and gestural components of Assiniboine and Nakota, (and others) stories. Plains Sign Talk was originally an intertribal trade language, but, like the individual tribal languages, it has fallen out of use. The columns for weight, legs, and torso have been removed from the staff, and columns more relevant to sign language have been added.

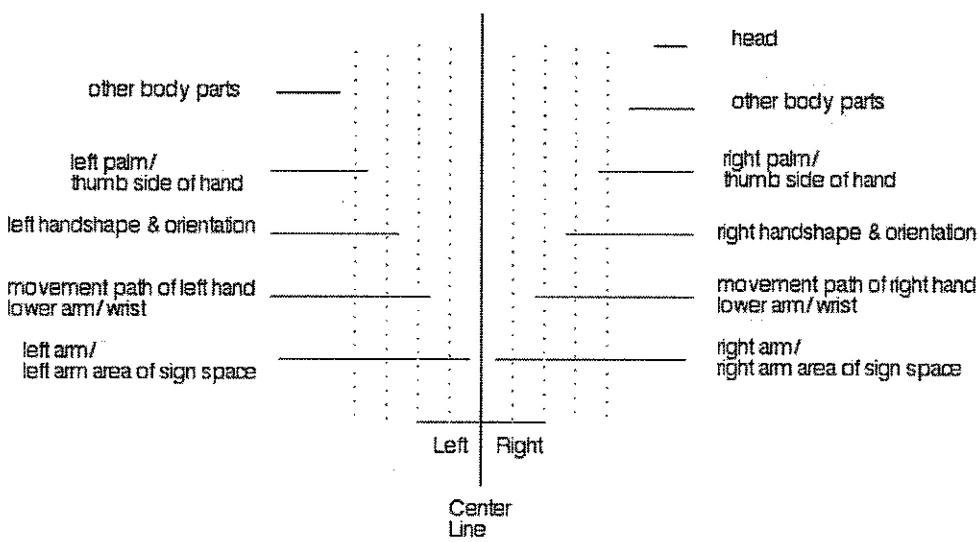


Figure 35. Farnell's modified laban staff

Farnell identified and defined twenty-four handshapes specific to PST using a combination of symbols for joints and for contraction and extension.

Farnell chose to describe changes in the location of the hands in terms of gross hand movement along a path rather instead of specifying the requisite arm movements.

While Farnell defined several areas of sign space, she admits that these regions are loose, and do not always correspond to phonemes.

4.2.3 Use of Labanotation for Transcribing Auslan

Joann Page also investigated the possibility of using dance notation to transcibe sign language. For reasons she did not enumerate, she determined that labanotation was superior to Benesh dance notation for her study of Auslan (Page 1995).

4.2.4 Deficiencies of Laban with Respect to the Inertial Positioning System

While labanotation may be more convenient for sign language transcription than the Stokoe notation, the movement-hold system, or HamNoSys, it is not ideal for use with the inertial positioning system. The first problems are a result of the organization of laban. The staff presupposes a location, and these locations are not clearly delineated. Because position is calculated from the displacement which results from movement, regions of sign-space must be clearly defined so that it is possible to determine where the hands are at any given time. A related problem that is not unique to labanotation is the correction calculation that must be performed in order to orient the movements of the hand in actual space with respect to the coordinate system of the notation system.

Laban was designed for use in notating all human movement. As a result, labanotation is more detailed than is practical for use with the inertial positioning system. The movement paths are more complex and the number of directional descriptors are more numerous than are necessary for notating the phonological parameters of ASL. Additionally, there are six degrees of intensity of each movement. Degree of intensity would be important in a purely phonetic transcription system[5], but it is not phonologically significant in most cases. Most of the movements in ASL to which severity would apply are articulated by the fingers, and thus would not be evaluated by the inertial positioning system. While magnitude of displacement is relevant to ASL, the semantic meaning is contained in the final location of the articulator. Because the algorithms for evaluating scaled length of movements have not been finalized, final location should be indicated instead of degree for non-standard magnitudes of displacement to ensure that the more meaningful property is evaluated.

Additional complications arise when the movements of both hands are taken into account. Labanotation specifies too many types of hand interactions, when the most relevant ones to ASL are contact and crossing. The inertial positioning system may not be able to differentiate between contact and close crossing, because the data gloves do not have pressure sensors; however, these interactions could simply be marked as proximity interactions, and their nature could be determined probabilistically by HMMs at a higher processing level. Labanotation also does not explicitly identify symmetrical movement paths of the hands. Of primary concern are identical movements (e.g. DEAD[6]) and movements reflected across the midsagittal plane (e.g. the two-handed sign CHILDREN). Labanotation would simply indicate the movement of each hand on the relevant side of

[5] Because a multi-level hierarchy is used to identify movements, the inertial positioning system cannot directly identify phonological parameters. A phonetic identification is a necessary intermediate step between the classification of movement data and the phonological classification used for sign glossing. For simplicity, only phonetic movements which directly map to phonological parameters should be considered.

[6] Although the orientation of the palms changes, the movement paths between the initial and final locations of the hands are identical. The change in orientation would be notated as such, and not as a movement,

the staff, leaving the reader to recognize the type of interaction or symmetry, but these should be explicitly stated for use with systems like the NJIT system.

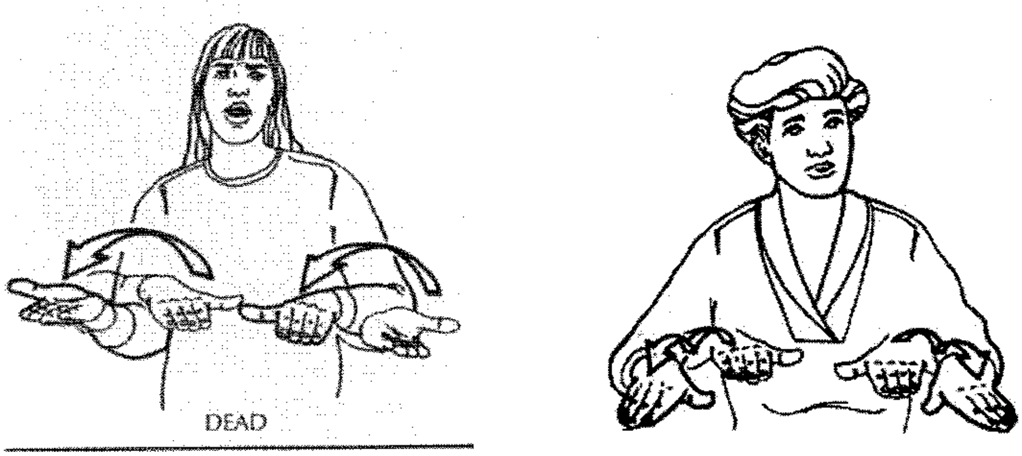


Figure 36. DEAD and CHILDREN

4.3 Farris's System

Michael Farris developed his own transcription system for ASL (Farris 1997). To my knowledge it is not widely used; however, its division of all parameters except nonmanuals can be used as guidelines for use with the handshape recognizer and the inertial positioning system. Farris's system divides each sign into Hand Configuration, Location, and Movement. Hand Configuration is divided into a subset of fifteen handshapes, eight contacting regions, and three hand interactions. Location is divided into an uncounted number of hand locations, fourteen body locations, and nine spatial locations. Movement is likewise divided, offering a choice of twelve path movements, ten internal movements, and six dynamics. It also includes five orientations and at least eight nonmanuals.

Farris describes phonetic vs. phonemic systems. He defines the syllabic structure of his system as a series of movements and locations, and allows signs to have the syllables M, LM, ML, and LML. This structure parallels Liddell and Johnson's Movement-Hold structure; Farris's locations are analogous to Liddell and Johnson's Holds. The Movement-Hold system identifies a different set of sign structures, allowing L, MLML, and MMML sequences while precluding the LM and LML sequences.

Farris later uses this structure to order the parameters of the sign as Hands, Location 1, Movement, and Location 2. The Hands parameter contains handshape and contacting region for both hands, as well as a contact or proximity marker, and an indication of whether the hands are symmetric for two handed-signs. Location 1 specifies hand, body, and spatial locations. The Movement parameter specifies initial quality of motion, direction, and overall quality of motion. Farris claims these parameters are sufficient, then lists elements of signs which would have to be transcribed if the transcription were made using another system, but which have been inherently specified by his choice of parameters.

4.4 Other Notational Systems

Labanotation, HamNoSys, and Farris's system are not the only notation systems for American Sign Language, simply ones that could be easily modified to transcribe movement and location for use in the Inertial Positioning System framework. Other transcription systems include West, Papaspyrou, Jouison, Benesh dance notations, SignFont, and Gestogramy. This list is far from complete, and should only be used as a starting point for anyone wishing to do further research on sign language notation. Sutton

SignWriting has also been used to represent sign language; however, it is a writing system and was not designed to record all phonological parameters of ASL.

4.5 How Transcription is Handled by Computer

There are several applications that are described as 'computer transcription' programs; however, they are primarily aids for phonological research. They provide a framework for a human to do the actual transcription. Programs such as MediaTagger require a human user to sift through recorded data, identifying the parameters of each sign, and painstakingly marking elements of interest to be included in the transcription (Senghas 2001). SyncWriter is a similar application (Hanke 2001). The same type of transcription work can be done using a spreadsheet like Excel, however Excel does not support video integration (Braem 2001). None of these programs has the capability of independently analyzing movement or location parameters, so they have been omitted from this discussion.

5.0 My Proposed System

The notation system I outline only specifies ways of representing location and movement parameters. Notation for orientation and handshape has been omitted because the identification of these parameters is performed by a separate instrumentation system. While the representations of all parameters must be simultaneous, the notations do not have to be interdependent.

5.1 Organization

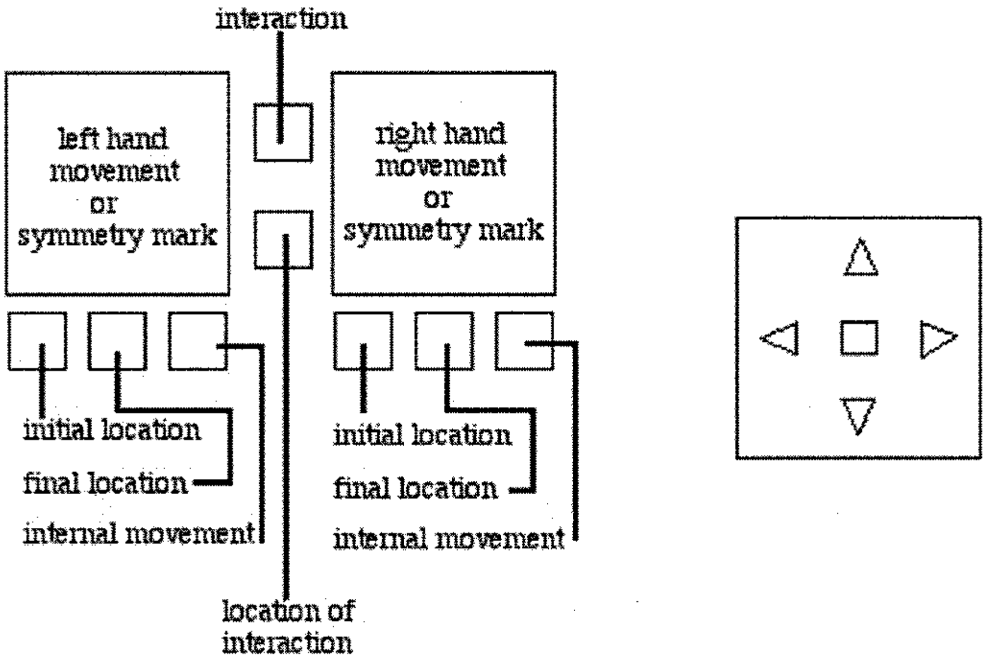


Figure 37. The general layout of my system.

Figure 37 shows the general layout of my notation system, and the layout for the movement of one hand. Both the dominant and the non-dominant hands are shown simultaneously, with a symmetry mark in the non-dominant hand region when the movements of the hands are identical. The left and right triangles indicate movements to the left and right; the up and down arrows indicate motion towards and away from the signer; and the square indicates motion in the vertical direction. These will be explained more fully in section 5.2. As a consequence of showing both hands in this arrangement, the left and right arrows must be reversed for each hand in order to keep the direction of motion in the notation consistent with the signed direction of motion. Since lateral movement in ASL is usually movement towards and away from the body's centerline, this is not an unreasonable convention, provided that the location notation is set up the same way. All movements are notated from the signers perspective.

Internal movement is written in a different block from the movement of the whole hand to serve as a reminder that it is a different type of movement, and is identified by another hardware system (i.e. the handshape recognizer). Internal movement is specified separately for each hand because both hands will not always have the same internal movement (e.g. STUDY-IN-A-HURRY).

Figure 38. STUDY-IN-A-HURRY. The dominant hand has a wiggling internal movement, but there is no internal movement of the non-dominant hand.

Interaction between hands is indicated, as well as the location of the interaction. If the location of interaction is a specific part of the hand, the notation for the handshape can be used in place of the regions of sign space defined in Section 5.3. Initial and final locations for the primary movements of the hands should be indicated with the locations in Section 5.3.

5.2 Movement

5.2.1 Requirements

Before a movement notation system can be developed, any movements that can be identified by the handshape recognition system must be separated from movements that must be classified by the inertial positioning system. The determination of movement path by the inertial positioning system is inherently computationally complex, so it is more computationally efficient to identify movements that can be represented as changes of handshape with the handshape recognizer.

Identification of movement is simplified by the organization of movement paths into a set of exhaustive, mutually exclusive paths. The notation system should reflect this organization, for ease of use by people who must work with both the notation and instrumentation systems. Because the set of paths should be exhaustive, the movements should be scalable; the equation of motion for each movement should not be affected by the time duration or size of the movements; however, it is possible to compensate for minor deviations from the defined movement by specifying initial and final locations for the movement.

Types of hand interaction (e.g. contact and crossing) and symmetries (e.g. reflection across the midsagittal plane) should be notated.

5.2.2 Movement Inventory

5.2.2.1 Internal Movement

Using the guidelines I defined in Section 5.2.1, all of the internal movements defined in the Movement-Hold system remain internal movements in my notation system.

For the purpose of identification, internal movements do not have to be specified in the notation system to a greater level of detail than outlined by Liddell and Johnson.

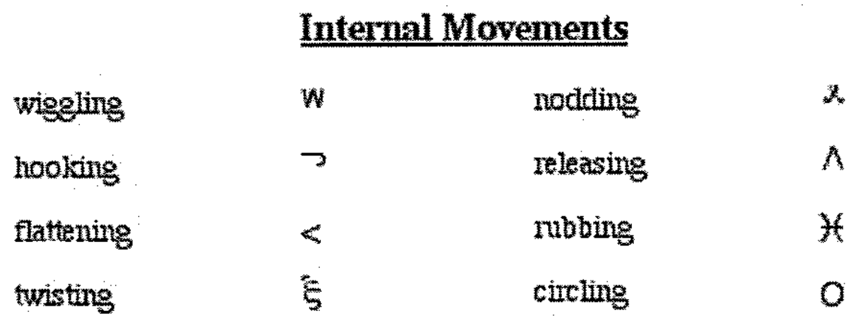


Figure 39. Inventory of internal movements

Movements that can be classified as changes in handshape (e.g. UNDERSTAND) are written as changes of handshape in the handshape notation system, so they have been omitted from this discussion.

5.2.2.2 Movement Paths

I define X,Y, and Z axes, where the positive X direction is towards the body, the positive Y direction is towards the opposite side of the body, and the positive Z direction is up.

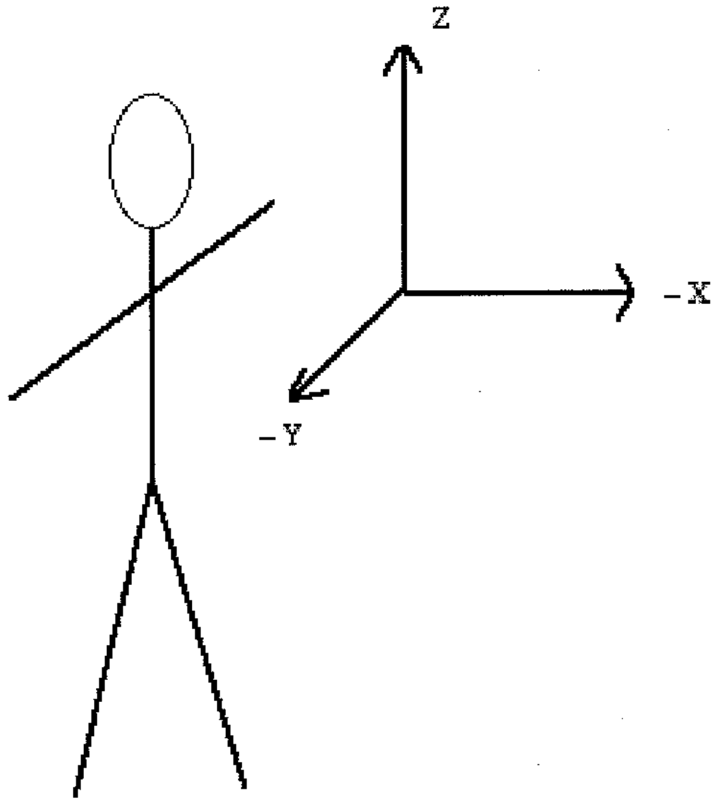


Figure 40. Axes for my system (shown for a right hand dominant signer).

The X and Y axes are the same as the up/down and left/right arrows in the notation system (see Figure #). The square represents movement in the Z direction. Similar to Labanotation, a filled in square represents movement down, and a striped square represents movement up; unlike laban, this convention does not apply to movement in the X and Y directions. Only the symbols in the direction of motion are drawn. Rectangular chords are written with two or three symbols, depending on whether the hand is moving in two or three dimensions.

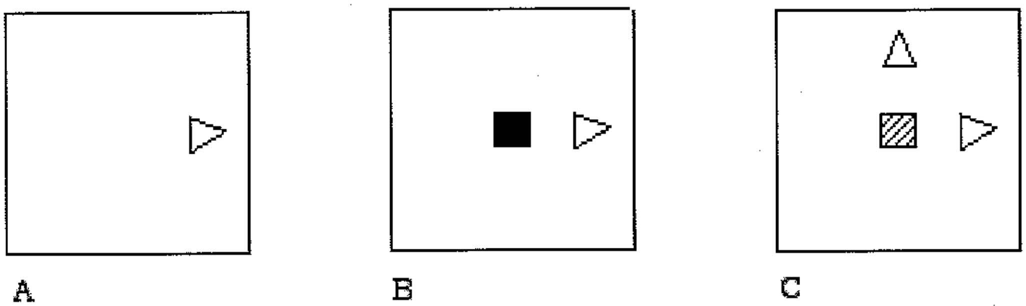


Figure 41. Examples of movement in one, two, and three dimensions for a right-handed signer. A: movement away from the center of the body (e.g. FORGET). B: diagonal movement down and to the right (e.g. LORD). C: movement up, to the right, and away from the body.

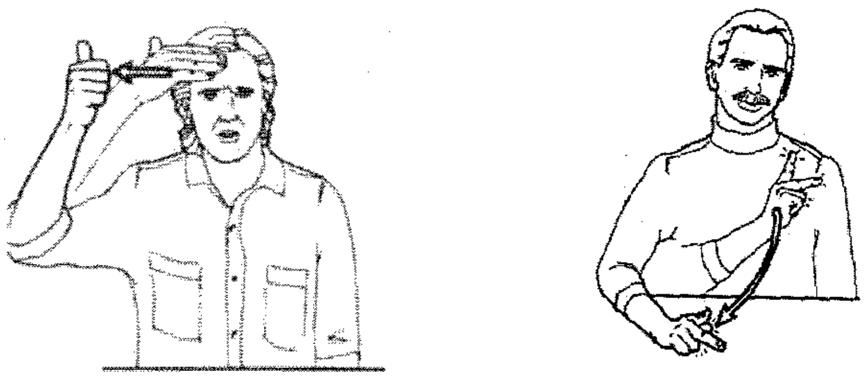


Figure 42. FORGET and LORD.

Angled paths are written as with the triangles in the two directions of motion, with a dot under the symbol indicating the first direction of travel. The first example in Figure 43 illustrates (for a right-handed signer) the angle path for PRINCESS. The hand moves on a horizontal path away from the center of the body, then straight down. The second example illustrates the reverse path, with the hand moving straight down, then moving outward from the center of the body.

Figure 43. Sample angle paths

Curved paths are indicated in a similar manner. The direction symbols are written, and the symbol of the direction of the curve is circled. No distinction is made between circular and elliptical paths, because there is no phonological difference between the two types of paths. Figure # shows the left hand and right hand movements of CLASS, and the movement of CHOMSKY, illustrating curves in the Y and Z directions.

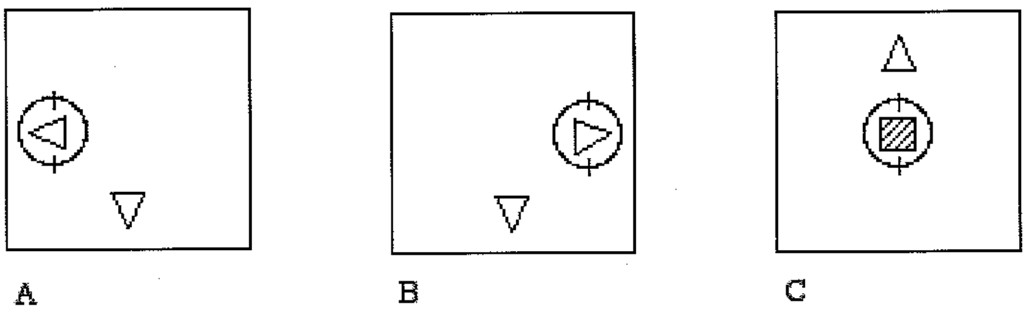


Figure 44. Example curves. A: the left hand movement of CLASS. B: the right hand movement of CLASS. C: the movement of CHOMSKY (either hand).

The portion of the circular path signed (i.e. quarter, half, three-quarters, or full)[7] is also indicated.

[7] I do not think the quarter and three-quarter paths are necessary, but I have included them for completeness.

Figure 45. Portions of the circular path

5.2.2.3 Symmetry and Interaction

I define one type of symmetry, reflection across the midsagittal plane, since it is the only symmetry that shows identical data from accelerometers on both hands. The symbol for this symmetry is written in place of the movement path for the non-dominant hand.

I also indicate crossing and contact as two handed interactions. Their symbols are written in the "interaction" box of the notation.

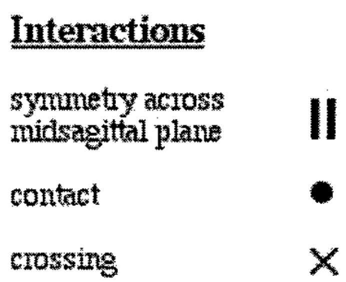


Figure 46. Symbols for symmetry and interaction

5.3 Location

5.3.1 Requirements

Regions of sign space must be discrete and mutually exclusive, so that position data can be mapped to a single location. The relationship between side of the body and signing hand should also be indicated because the position of each hand will first be identified with respect to that hand, then mapped to an absolute location in relation to the body.

5.3.2 Location Inventory

I have kept the fourteen regions of sign space adapted from Stokoe's model, and added a region above the head, for a total of fifteen primary regions of sign space. In a manner similar to the division of Farris's system, these regions have been subdivided into proximal and distal and left and right zones to provide relevant data for the classification of location by the inertial positioning system. This subdivision will aid in the identification of movement paths. When the specific zone has no semantic or phonological significance, the region of sign space should be indicated. When identifying location, the inertial positioning system will default to the region of sign space.

Table 9. Divisions of Sign Space.

Symbol	Zone	Region of Sign Space	Default
□			Face
⊓	Dominant[8] upper face	Upper face	Face
⊓	Non-dominant upper face	Upper face	Face
▬	Dominant mid face	Mid face	Face
—	Non-dominant mid face	Mid face	Face
⊔	Dominant lower face	Lower face	Face
⊔	Non-dominant lower face	Lower face	Face
❙	Dominant side face	Dominant Side Face	Face
	Non-dominant	Non-dominant side face	Face

[8] "Dominant" is a misnomer referring to the side of the body of the signing hand. For one-handed signs, the "dominant" side is the same as the dominant hand. For two-handed signs, there are actually two "dominant" sides, one for each hand.

|	Side Face		
∩	Neck	Neck	Neck
Ω	Shoulder	Shoulder	Shoulder
T	Upper arm	Upper arm	Upper arm
+	Forearm	Forearm	Forearm
⊥	Wrist	Wrist	Wrist
[]			Null Space
Λ	Proximal Dominant High Null Space	Dominant High Null Space	Null Space
[**Λ**]	Distal Dominant High Null Space	Dominant High Null Space	Null Space
Λ	Proximal Non-Dominant High Null Space	Non- Dominant High Null Space	Null Space
[Λ]	Distal Non-Dominant High Null Space	Non- Dominant High Null Space	Null Space
V	Proximal Dominant Low Null Space	Dominant Low Null Space	Null Space
[**V**]	Distal Dominant Low Null Space	Dominant Low Null Space	Null Space
V	Proximal Non-Dominant Low Null Space	Non- Dominant Low Null Space	Null Space
[V]	Distal Non-Dominant Low Null Space	Non- Dominant Low Null Space	Null Space

Contacts will be determined probabilistically using HMMs.

6.0 Conclusion

The movement and location notation system I developed for use with the inertial positioning system uses 22 symbols to notate movement, and 23 symbols to notate location. These values are comparable to a small syllabary (when combined), or two alphabets. This limited number of symbols, which are mostly iconic, can be used to transcribe movements at the level of detail necessary for the inertial positioning system. While there are many other notation systems that could accomplish this goal adequately, most would require modification in order to express all the relevant movement paths and locations without expressing unnecessary movements.

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Appendix A
Bibliography of Figures and Tables

Figure 1
Hat-mounted camera images from "Using multiple sensors for mobile sign language recognition," by H. Brasher, T. Starner, P. Lukowicz, and H. Junker, 2003, *Seventh IEEE International Symposium on Wearable Computers,* p. 48. Copyright 2003 by IEEE.

Figure 2
SHOWER from *Signing Naturally: Student workbook, level I,* by L. Cahn, 1993, p. 165, Copyright 1993 by DawnSignPress.

GRANDFATHER from *Signing Naturally: Student workbook, level I,* by L. Cahn, 1993, p. 47. Copyright 1993 by DawnSignPress.

Figure 4
FAMILY from http://www.lifeprint.com/asl101/pages-layout/initialization.html

Figure 5
CHAIR from http://www.ling.upenn.edu/courses/Spring_2001/ling001/asl_sit-chair.jpg

NAME from http://www.istc.cnr.it/mostralis/img/lingua01.gif

Figure 6
SUMMER and DRY from *Linguistics of american sign language: An introduction (3rd ed.),* by C. Valli and C. Lucas, 2000, p. 20. Copyright 2002 by Gallaudet University.

Figure 7
SIT and CHAIR from http://www.ling.upenn.edu/courses/Spring_2001/ling001/asl_sit-chair.jpg

Figure 8
BALL from *Signing Naturally: Student workbook, level I,* by L. Cahn, 1993, p. 27, Copyright 1993 by DawnSignPress.

Figure 10
PRINCESS from *Signing Naturally: Student workbook, level I,* by L. Cahn, 1993, p. 147. Copyright 1993 by DawnSignPress.

Figure 17
COLOR from *Signing Naturally: Student workbook, level I,* by L. Cahn, 1993, p. 36. Copyright 1993 by DawnSignPress.

GO OUT from *Signing Naturally: Student workbook, level I,* by L. Cahn, 1993, p. 61. Copyright 1993 by DawnSignPress.

WHERE from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 5, Copyright 1993 by DawnSignPress.

YES from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 15. Copyright 1993 by DawnSignPress.

WHAT TO DO from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 60. Copyright 1993 by DawnSignPress.

MONEY from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 117. Copyright 1993 by DawnSignPress.

BASEMENT from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 84. Copyright 1993 by DawnSignPress.

Figure 18
Major finger orientations from http://www.sign-lang.uni-hamburg.de/Projekte/HamNoSys/HamNoSysErklaerungen/englisch/Contents.html

Figure 19
Palm orientations from http://www.sign-lang.uni-hamburg.de/Projekte/HamNoSys/HamNoSysErklaerungen/englisch/Contents.html

Figure 20
Direction of straight line movement from http://www.sign-lang.uni-hamburg.de/Projekte/HamNoSys/HamNoSysErklaerungen/englisch/Contents.html

Figure 22
Symmetries from http://www.sign-lang.uni-hamburg.de/Projekte/HamNoSys/HamNoSysErklaerungen/englisch/Contents.html

Figure 24
Laban symbols for limbs and joints from *Do you see what I mean?*, by B. Farnell, 1995, p. 311. Copyright 1995 by the University of Texas Press.

Figure 25
Laban symbols for areas of the body from *Do you see what I mean?*, by B. Farnell, 1995, p. 311. Copyright 1995 by the University of Texas Press.

Figure 32
Symbols for extension, contraction, dynamics, and repetition from *Do you see what I mean?*, by B. Farnell, 1995, p. 318. Copyright 1995 by the University of Texas Press.

Figure 34
CAR-DRIVE-BY from *Linguistics of american sign language: An introduction (3rd ed.)*, by C. Valli and C. Lucas, 2000, p. 80. Copyright 2002 by Gallaudet University.

Figure 35
Farnell's modified laban staff from *Do you see what I mean?,* by B. Farnell, 1995, p. 317. Copyright 1995 by thhe University of Texas Press.

Figure 36
DEAD from *Linguistics of american sign language: An introduction (3rd ed.)*, by C. Valli and C. Lucas, 2000, p. 154. Copyright 2002 by Gallaudet University.

CHILDREN from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 44, Copyright 1993 by DawnSignPress.

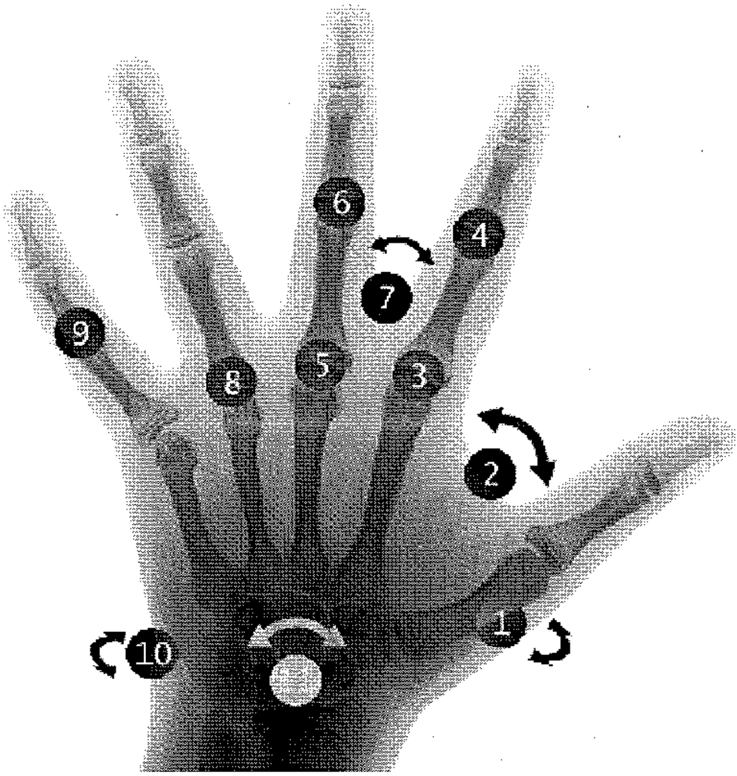
Figure 38
STUDY-IN-A-HURRY from *Linguistics of american sign language: An introduction (3rd ed.)*, by C. Valli and C. Lucas, 2000, p. 108. Copyright 2002 by Gallaudet University.

Figure 42
FORGET from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 15. Copyright 1993 by DawnSignPress.

LORD from *Signing Naturally: Student workbook, level I*, by L. Cahn, 1993, p. 147. Copyright 1993 by DawnSignPress.

Tables 7-8
Data from http://www.sign-lang.uni-hamburg.de/Projekte/HamNoSys/HamNoSysErklaerungen/englisch/Contents.html

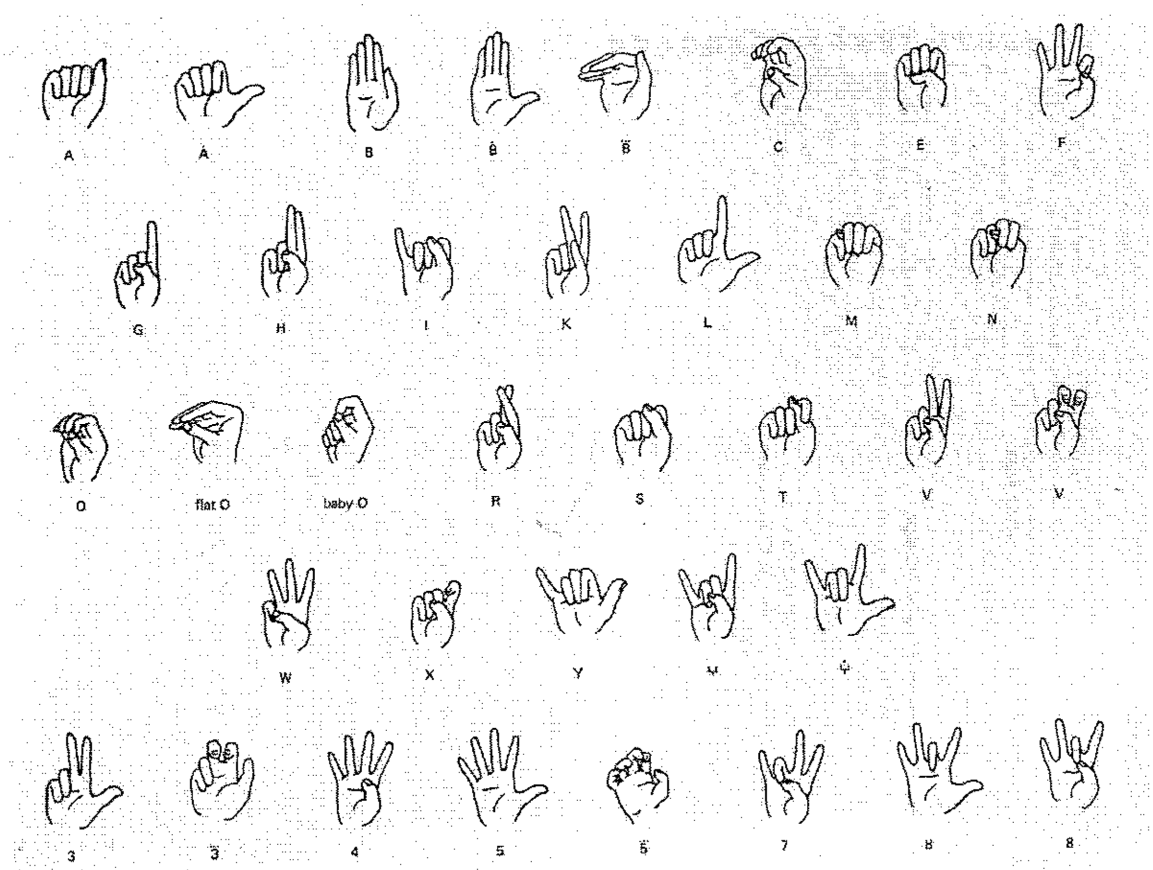
Appendix B
Sensors of the Cyberglove Used by the Handshape Recognition System



1. Thumb Rotation
2. Thumb Abduction
3. Index Metacarpophalangeal
4. Index Proximal Interphalangeal
5. Middle Metacarpophalangeal
6. Middle Proximal Interphalangeal
7. Index-Middle Abduction
8. Ring Metacarpophalangeal
9. Little Proximal Interphalangeal
10. Wrist Pitch
11. Wrist Yaw

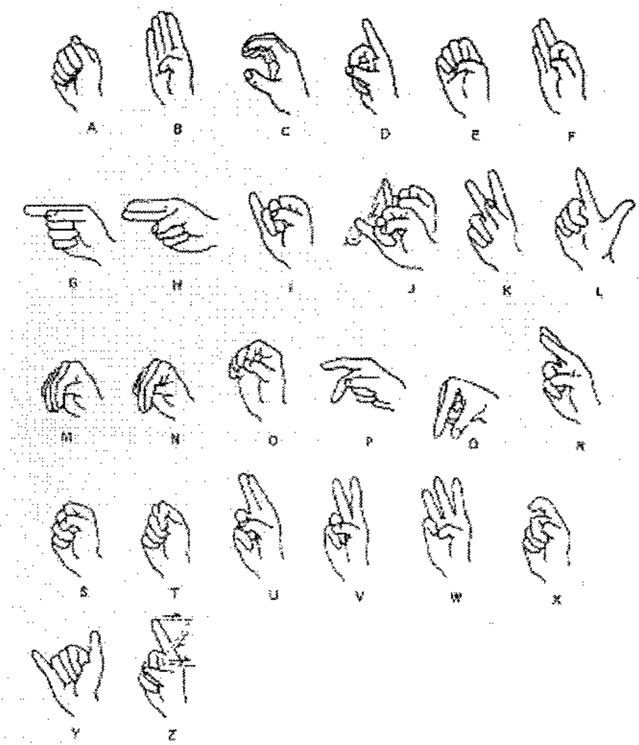
From *ASL translation systems*, by B. Galego, J. Lallo, M. Paulter, and R. Shinde, 2005.

Appendix C
Handshapes of ASL



Handshapes of ASL from *American sign language and sign systems*, by R. B. Wilbur, 1979, p. 16. Copyright 1979 by University Park Press.

Appendix D
The Manual Alphabet



ASL manual alphabet from *American sign language and sign systems*, by R. B. Wilbur, 1979, p. 18. Copyright 1979 by University Park Press.

Appendix D
Inventory of Stokoe Notation

Tab symbols

1. Ø zero, the neutral place where the hands move, in contrast with all places below
2. ◯ face or whole head
3. ⌒ forehead or brow, upper face
4. △ mid-face, the eye and nose region
5. ◡ chin, lower face
6. 3 cheek, temple, ear, side-face
7. Π neck
8. [] trunk, body from shoulders to hips
9. \ upper arm
10. √ elbow, forearm
11. a wrist, arm in supinated position (on its back)
12. D wrist, arm in pronated position (face down)

Dez symbols, some also used as tab

13. A compact hand, fist; may be like 'a', 's', or 't' of manual alphabet
14. B flat hand
15. 5 spread hand; fingers and thumb spread like '5' of manual numeration
16. C curved hand; may be like 'c' or more open
17. E contracted hand; like 'e' or more claw-like
18. F "three-ring" hand; from spread hand, thumb and index finger touch or cross
19. G index hand; like 'g' or sometimes like 'd'; index finger points from fist
20. H index and second finger, side by side, extended
21. I "pinkie" hand; little finger extended from compact hand
22. K like G except that thumb touches middle phalanx of second finger; like 'k' and 'p' of manual alphabet
23. L angle hand; thumb, index finger in right angle, other fingers usually bent into palm
24. 3 "cock" hand; thumb and first two fingers spread, like '3' of manual numeration
25. O tapered hand; fingers curved and squeezed together over thumb; may be like 'o' of manual alphabet
26. R "warding off" hand; second finger crossed over index finger, like 'r' of manual alphabet
27. V "victory" hand; index and second fingers extended and spread apart
28. W three-finger hand; thumb and little finger touch, others extended spread
29. X hook hand; index finger bent in hook from fist, thumb tip may touch fingertip
30. Y "horns" hand; thumb and little finger spread out extended from fist; or index finger and little finger extended, parallel
31. 8 (allocheric variant of Y); second finger bent in from spread hand, thumb may touch fingertip

Sig symbols

32. ^ upward movement (vertical action)
33. v downward movement (vertical action)
34. N up-and-down movement (vertical action)
35. > rightward movement (sideways action)
36. < leftward movement (sideways action)
37. z side to side movement (sideways action)
38. ⊤ movement toward signer (horizontal action)
39. ⊥ movement away from signer (horizontal action)
40. I to-and-fro movement (horizontal action)
41. a supinating rotation (palm up) (rotary action)
42. D pronating rotation (palm down) (rotary action)
43. ω twisting movement (rotary action)
44. η nodding or bending action
45. □ opening action (final dez configuration shown in brackets)
46. # closing action (final dez configuration shown in brackets)
47. ɚ wiggling action of fingers
48. @ circular action
49.) (convergent action, approach (interaction)
50. × contactual action, touch (interaction)
51. ⌶ linking action, grasp (interaction)
52. + crossing action (interaction)
53. ⊙ entering action (interaction)
54. ÷ divergent action, separate (interaction)
55. " interchanging action (interaction)

From *Linguistics of american sign language: An introduction (3rd ed.)*, by C. Valli and C. Lucas, 2000, p. 27. Copyright 2002 by Gallaudet University.