The signing space for the synthesis of directional verbs in NGT

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Preface

This paper describes an individual contribution to a larger project executed in close collaboration with [1] and [2]. The first parts of these three papers describe the overall project and were jointly written, making them largely identical. Section 1.2 describes the global research question, and sections 2 and 3 provide theoretical context and set up a hypothesis. Section 5.1.1 shows the overall program created, including the components of the other projects, and section 5.2.1 evaluates the result. These previously mentioned chapters and sections have been written in joint collaboration with [1] and [2]

An introduction to and motivation for the overall project are provided in section 1. Section 4.2 discusses and addresses the goals specific to the research of this paper only, and sections 5.1.2 and 5.2.2 pertain to the results and the evaluation of this research. Finally, in section 6 a conclusion and discussion of this research is given. These sections regard individual efforts, and have therefore been written individually. For more specific information about the other components of this project, the reader is advised to read the other two aforementioned papers. However, it is not necessary to have read them to understand this paper.

Abstract

Hearing parents who have deaf children are often put in a difficult position. They most likely know no sign language and resources for learning are limited and expensive. Research into sign language translation and synthesis has increased in the past two decades, due to a growing interest into making public spaces and services more accessible to Deaf people [3]. This research shows the potential of a translator from Dutch to Dutch sign language (NGT) using a sign language avatar. In particular the focus lies on an implementation of directional verbs, a critical grammatical component of sign language. The implementation, though limited, shows real potential.

Contents

1 Introduction **9**
- 1.1 Introduction and Context . . . 9
- 1.2 Aim . . . 9

2 Background **10**
- 2.1 History of Dutch sign language . . . 10
- 2.2 Grammar of Dutch Sign Language . . . 11
  - 2.2.1 Handshape . . . 11
  - 2.2.2 Orientation . . . 12
  - 2.2.3 Location . . . 12
  - 2.2.4 Movement . . . 13
  - 2.2.5 Non-manuals . . . 13
  - 2.2.6 Classifiers . . . 15
  - 2.2.7 Syntax . . . 15
  - 2.2.8 Signing Space . . . 16
- 2.3 Previous Research on Sign Language Translation and Synthesis . . . 17

3 Global Methodology **18**
- 3.1 Avatar Software . . . 18
  - 3.1.1 Hamburg Notation System . . . 18
  - 3.1.2 Signing Gesture Markup Language . . . 19
  - 3.1.3 JASigning . . . 21
- 3.2 Lexical Resources . . . 21
- 3.3 Grammatical Resources . . . 22
- 3.4 Overview Components . . . 22

4 Signing Space Methodology **23**
- 4.1 Goal . . . 23
- 4.2 Approach . . . 23
  - 4.2.1 Indexing . . . 23
  - 4.2.2 Adapting directional verbs . . . 23

5 Results and evaluation **26**
- 5.1 Results . . . 26
  - 5.1.1 Global Results . . . 26
  - 5.1.2 Signing Space Results . . . 27
- 5.2 Evaluation . . . 29
  - 5.2.1 Global Evaluation . . . 29
  - 5.2.2 Individual Evaluation . . . 29

6 Conclusion and Discussion **35**
- 6.1 Conclusion . . . 35
- 6.2 Discussion . . . 35
- 6.3 Future Work . . . 35

A Hamnosys Handshapes **38**

B HamNoSys Locations **39**

C JASigning User Interface **40**

D Evaluation Sentences **41**

E Evaluation Form **42**

F Global Results **44**

1 Introduction

1.1 Introduction and Context

In the Netherlands 1 in 1000 children are born deaf or go deaf within their first three years of life. Approximately 90 - 95% of those children are born to hearing parents [4]. These parents will most likely have little or no experience with Dutch sign language (NGT), the primary language of the Deaf [1] community in the Netherlands. This means that they have no easy way of communicating with their deaf children. In addition, these children cannot simply learn the language from their parents and it is critical for their development that they learn some form of language during the early stages of their life. A study on Deaf adults showed that the age at which they acquired sign language greatly affects their ability to understand the meaning of a signed sentence and thus affects their comprehension of sign language [5]. There is a common misconception that sign languages are simply a signed version of their spoken counterparts. Sign languages are, however, separate languages that developed separately from spoken languages and thus have their own grammar [6]. It is therefore not easy for a hearing person to learn sign language. Resources for learning NGT are limited and often expensive, making it especially difficult for hearing parents with a deaf child to learn how to communicate with them.

Communication with hearing people can be difficult for Deaf people. When trying to communicate with them, a hearing person will most likely resort to writing down what they are trying to say. However, as mentioned earlier, NGT is inherently different to Dutch and is therefore not easy to learn for Deaf people. A study by Wauters, van Bon and Tellings, found that in the Netherlands the reading comprehension of the average deaf child is far below that of a hearing child [7]. Written communication can therefore be a struggle for Deaf people, thus not always making it a viable option. In other situations hearing people may make use of an interpreter, a hearing person who knows sign language, to communicate with Deaf people. It is however not feasible to always have an interpreter present for such communication and moreover interpreting is tiring, meaning that interpreters need breaks during long conversations. In the case of websites and announcements such as at train stations, videos of a person signing the written or spoken text are sometimes used. The downside to this method is that it is very inflexible, as anytime the information that needs to be conveyed changes, the videos have to be re-filmed.

An animated avatar that signs translations of Dutch into NGT would offer a solution to both issues. It could help people learn NGT and also function as a tool for easing communication between Deaf and hearing people in general. There are, however, no such publicly available tools, even though an increasing amount of research has been done into sign language translation and synthesis [3].

1.2 Aim

The goal of the project is to build the basis for a tool in which a user can enter a Dutch sentence and in return see a correct translation of this sentence in Dutch sign language (NGT), by an animated avatar. This will prove a valuable resource for people attempting to learn a sign language and/or communicate with a Deaf person. The project aims to answer the question "What are the necessary components for a system that uses an avatar to translate a Dutch sentence to Dutch sign language?"

Part of the question, namely how to translate from Dutch to NGT, has been covered in previous research [8, 9, 10]. Therefore, this research will focus on the production of NGT from glosses, which are textual representations of signs (e.g. HOUSE[2] is the gloss of the sign that means 'house'). The goal of this project is to create a proof of concept with a limited vocabulary that allows a user to input a glossed NGT sentence, whose translation will be signed by an avatar. This avatar would display all the attainable essential elements of the translation.

[1] As per convention this paper uses Deaf when referring to people who are part of the Deaf community and speak sign language, and deaf when referring to those with the auditory impairment.

[2] Glosses are in capital letters to illustrate that these words are signed and not spoken

The remainder of this paper is structured as follows: section 2 discusses the theoretical foundation of the workings of NGT and previous research done in the field of sign language translation and synthesis. In section 3, a hypothesis for the research question is formed on the basis of section 2, and a global methodology is described for the development of the necessary components. Section 2.2.8 focuses on the signing space by formulating specific goals for its development and illustrating the implementation of these goals in detail. In section 5, both global and individual results are presented and evaluated. Section 6 delivers a critical reflection on the results and a discussion of open issues and future work.

2 Background

It is a common misconception that there is a universal sign language. Although similarities can be found in signs for words that are globally characterised in the same manner (e.g. the sign for 'house' is identical in multiple sign languages - see Figure 1), parallel to spoken languages, sign languages have evolved independently of each other and impose their own distinctive set of grammatical rules [11]. This is clearly illustrated by American Sign Language and British Sign Language: " despite the fact that [they] are surrounded by the same spoken language, they are mutually unintelligible", and therefore "most often named for the country or area in which they are used", as they are so distinctively unique [11]. Sign Language of the Netherlands (NGT) is no exception to this rule: it even has five official dialects [12].

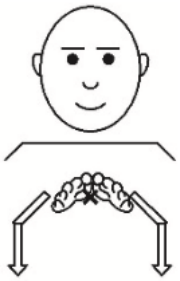


Figure 1: The sign for HOUSE [6]

2.1 History of Dutch sign language

Five Deaf institutes have been established in the Netherlands between 1790 and 1911, in different regions of the country. However, the use of sign language in Dutch Deaf-education was banned between 1915 and 1980 [12]. This ban was due to the concept of 'oralism', "the practice of teaching Deaf students through spoken language using amplification devices and lip-reading, to the exclusion of all sign language communication" [13]. It was believed that it was better for deaf children to be educated in solely spoken language, as the usage of signs would inhibit the development of spoken language [12]. Nevertheless, Deaf people still signed amongst each other. The combination of the previous and the fact that the five Deaf institutes in the Netherlands barely communicated with each other at the beginning of the 20th century caused the different dialects in NGT [12]. Currently, NGT is used in Deaf-education and recognised as a language both politically and socially, but not legally [12]. The Deaf community is taking action to legally recognise NGT as an official language in the Netherlands [14].

2.2 Grammar of Dutch Sign Language

Figure 2: The signing space [6]

NGT, like all other sign languages, is a visual-spatial language: it is "articulated by using the hands, face, and other parts of the body, and all these articulators are visible... signs are articulated on the body or in space close to the body" [6]. Figure 2 shows the signing space used in NGT, which will be explained in section 2.2.8.

The phonology of NGT consists of four aspects: handshape, orientation, location and movement. When discussing SL, the term *phonology* is used "despite its sound-based etymology, in order to emphasise that the same level of structure exists in spoken language." [15].

2.2.1 Handshape

(a) A 'c' handshape (b) A 'v' handshape (c) A 't' handshape

Figure 3: Different kinds of handshapes [6]

For handshape, there is a distinction between which fingers are selected (active) and the position of these fingers [6]. Examples are shown in Figure 3. In Figure 3a, all four fingers are selected; in Figure 3b, the index- and middle finger are selected; and in Figure 3c, the little finger, ring finger, and middle finger are not selected, as they are not the 'active' fingers in this case. Selected fingers "can make contact with the body, the head, or the other hand and arm; can adopt a special position (curved, bent, closed, spread); can move (open and close)" [6]. The position of selected fingers describe: "curving of the fingers [Figure 3a]; spreading of the fingers [Figure 3c]; an aperture relation between the thumb and the selected fingers [Figure 3c]" [6].

2.2.2 Orientation

(a) The orientation for the sign EASY

(b) The orientation for the sign SUPPOSE-THAT

Figure 4: Different kinds of orientations in NGT [6]

The orientation of a sign can be described by "identifying the part of the hand that points towards the location of the sign", the parts of the hand being the "palm, the back of the hand, the thumb side, the little finger side, the wrist side, and the tips of the fingers" [6]. In Figure 4, the location of both signs is the same (the chin), but in Figure 4a, the palm points to the location, and in Figure 4b, the thumb side of the hand points to the location [6].

2.2.3 Location

(a) The location for the sign CRUEL

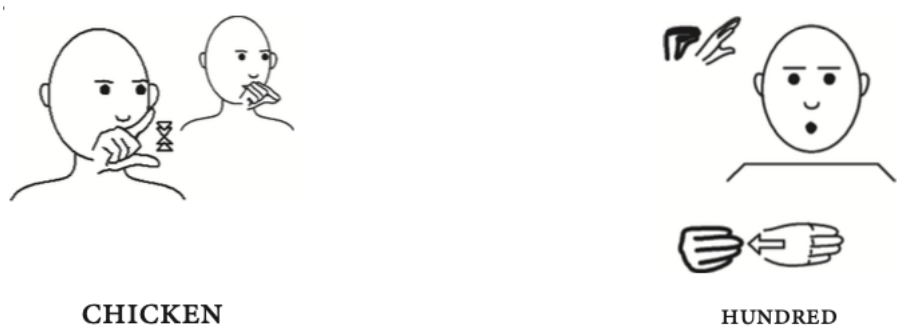
(b) The location for the sign SWEET

Figure 5: How location can affect the meaning of a sign - British Sign Language [6]

The location of the sign is where in the signing space (Figure 2) the sign is articulated. There are four main locations: "the head, the upper body, the non-dominant (or weak) hand, and the neutral space", the neutral space being the space in front of the body [6]. The location of a sign is an important distinction for its meaning. An example can be seen in Figure 5, where Figure 5a displays the sign for CRUEL[3], and Figure 5b the sign for SWEET: two contrasting meanings, yet almost identical signs.

[3]Glosses (the meanings of signs) are conventionally written in uppercase to make it clear that these words are not spoken, but signed

2.2.4 Movement



(a) The movement for the sign CHICKEN

(b) The movement for the sign HUNDRED

Figure 6: Different kinds of movements in NGT [6]

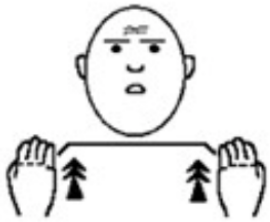
Movements can be divided into two types: "movements of the fingers and wrist (hand-internal movements and orientation changes) and movements of the entire hand (path movements)" [6]. One example of a path movement is the sign SUPPOSE-THAT in Figure 4b, where the whole hand moves towards the chin. Figure 6 shows two additional examples: Figure 6a illustrates hand-internal movements (only the fingers move), and Figure 6b displays a combination of a path- and a hand-internal movement: the fingers close while the entire hand moves [6].

2.2.5 Non-manuals

(a) The sign BROER and ZUS [16]

(b) Non-manuals for the sign IDIOT [6]

(c) Non-manuals for the sign WANT^NOT [17]



(d) Non-manuals for the sign WHY [16]

Figure 7: Non-manuals in NGT

The non-manuals are composed of "form elements that relate to the posture of the body and the head, facial expressions, and certain movements or configurations of the mouth", and are vital components of a sign [6]. Figure 7 illustrates four different types of non-manuals: mouthings, mouth gestures, a headshake, and

general facial expression. Figure 7a shows identical the manual component for the signs BROTHER and SISTER, the distinction lies in whether the signer uses the mouthing 'broer' (brother) or 'zus' (sister). Figure 7b displays the mouth gesture accompanying the sign IDIOT: "a lax tongue hanging slightly out of the mouth while some air is being blown out" [6]. Figure 7c accentuates the head shake for the sign WANT-NOT [4]; without it the sign would not be valid. Lastly, Figure 7d illustrates the slightly raised chin and furrowed eyebrows that are tied to asking a content question (WH question) in NGT.

When asking a question in certain spoken languages, including Dutch and English, speakers use intonation to differentiate a question from a statement. A sentence like: 'I do the dishes', can be a statement when pitch is gradually lowered, but a question if the pitch is gradually raised. NGT is similar, except instead of adjusting intonation, signers adjust non-manuals [6]. To indicate a sentence is a polar question, eyebrows are slightly raised, and the head pushed slightly in front of the torso [18]. Examples (1) and (2) shows the difference between a statement and a polar question, to exemplify that solely the addition of non-manuals can completely change the meaning of a sentence. The non-manual marker changes Statement (1) into Question (2).

(1) ***Statement***

IK AFWASSEN
I do.the.dishes

'I do the dishes'

(2) ***Polar Question***

IK AFWASSEN (accompanied by raised eyebrows and the head pushed slightly forward)
I do.the.dishes

'I do the dishes?' (accompanied by a raise in pitch)

The vital importance of non-manuals is also visible in negation. Regarding negative constructions, NGT is a non-manual dominant sign language, which means the non-manual marker is more important than the manual one, and the latter is usually omitted [6]. When manual marker is used, however, this is usually for emphasis, which can be seen in Examples (3) and (4). A signer would use Sentence (3) to clarify that they are not going to the zoo tomorrow. They would use Sentence (4), however, to clarify the same point more sternly [19]. As a final note, the non-manuals discussed in the previous paragraphs are not an exhaustive list. Other non-manuals include (but are not limited to): a change of posture to fit the situation, a head nod for affirmation, a puffing of the cheeks to indicate that the subject matter is large.

(3) ***Negative Construction***

MORGEN WIJ DIERENTUIN GAAN (with headshake)
tomorrow we zoo go

'We're not going to the zoo tomorrow.'

(4) ***Negative Construction with emphasis***

MORGEN WIJ NIET DIERENTUIN GAAN (with headshake)
tomorrow we not zoo go

'We're really not going to the zoo tomorrow.'

[4] A gloss consisting of multiple words separated by a hyphen denotes a single sign

2.2.6 Classifiers

(a) BOOK-FALLS (b) PERSON-FALLS

Figure 8: Classifiers for the verb TO-FALL in NGT [20]

In NGT (and other sign languages), the handshape of a sign may vary with different subjects. Figure 8 illustrates this with the NGT sign TO-FALL. In Figure 8a, the handshape is flat, resembling the book that is falling. Figure 8b, on the other hand, displays a handshape resembling the legs of a person, to indicate that a human is falling. his process is called 'classification', and is restricted to localisation in the signing space and verbs of motion [6]. Classifiers are an important aspect of sign languages as they simplify conversation. A signer may localise a character with the person-classifier, and later on refer to this character by simply indicating the same classifier in the previously defined location.

2.2.7 Syntax

The syntax of Dutch and NGT are inherently different. Example (5) below demonstrates the difference in constituent order, adjective order, and verb conjugation. Firstly, NGT has a basic sentence order of Subject-Object-Verb (SOV), which indicates that the subject, object, and verb usually appear in that respective order [6]. Dutch, on the other hand, has a sentence order of Subject-Verb-Object (SVO), switching around the object and the verb. Likewise, modifiers are deployed in a different order, such as the adjective succeeding the noun in Dutch, whereas the converse is usually true in NGT [6, 21]. Verb conjugation is not influenced by tenses, and only happens in the context of agreement (further explained in section 2.2.8). It only affects the manual component of the sign, the gloss and nonmanuals do not change.

(5) [MAN OUD]$_S$ [HUIS]$_O$ [LOPEN]$_V$
'[De oude man]$_S$ [loopt naar]$_V$ [huis]$_O$.'
'The old man walks home.'

With negative and interrogative constructions, the location of the manual marker differs from the location of the respective Dutch word. A content question (shown in Example 6), has the WH-sign (signed counterpart of content question words) in the final sentence position. WH-doubling (the doubling of the WH-sign) is used often for emphasis, resulting in a WH-sign in initial and final sentence position [6]. Furthermore, negative constructions (demonstrated in Example 7), have the manual marker positioned usually succeeding the subject, or at final sentence position [22].

(6) ***Content Question***

(WIE) BEURT_HEBBEN WIE
(who) turn.has who

'Whose turn is it?'

(7) ***Negation***

IK NOOIT BROCCOLI ETEN/ IK BROCCOLI ETEN NOOIT
I never broccoli eat/ I broccoli eat never

'I never eat broccoli.'

2.2.8 Signing Space

In sign language the signing space (Figure 2) is used to keep track of the conversation and make communication smoother. When localising entities in the signing space, the signer will do this logically and most likely based on their own perspective. This means that if the signer sees a tree to the right of a house, the signer will localise the tree to the right of the house in the signing space. By localising entities in the signing space, many aspects of communication are simplified.[6]

During conversations people will often reference something or someone mentioned before instead of repeating it. It is unlikely that someone would say the following: 'Bella is a young woman and Bella is pretty. Bella had blue earrings, but Bella lost the blue earrings.' Instead 'Bella is a young woman and she is pretty. She had blue earrings, but she lost those.' sounds much more natural. This is because of the use of personal and demonstrative pronouns, the former being words like 'I', 'she' and 'it', and the latter words such as 'that','those' and 'these'. In sign languages a similar method is used, but those pronouns are replaced by a pointing gesture, called an INDEX [6]. The pointing gesture is made towards the place (locus) in the signing space that the entity being referred to has been localised or where they are in the surrounding space (e.g. for 'I' the signer simply points towards themselves). Figure 9 shows the loci that are most commonly used in sign language. Loci 1 and 2 are always present (the signer and the interlocutor), but loci $3a$ and $3b$ are used for referents that do not have to be present. So the sentence 'I like you' would be translated in sign language to INDEX_1 INDEX_2 LIKE. An INDEX can also be used to distinguish between far away (*there*) and nearby (*here*) locations. The former is performed by making a pointing gesture short and down-ward and the latter by making the gesture arc-shaped, longer and forwards.

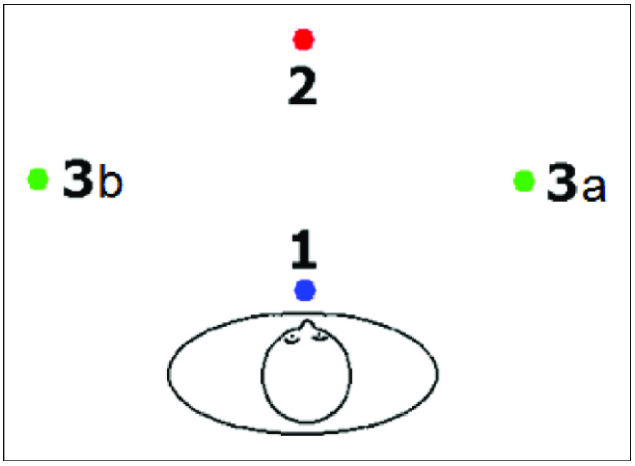


Figure 9: indices in the signing space [23]

Another important use of the signing space originates from the fact that in general, sign languages make little use of adpositions (prepositions and postpositions) to convey temporal (e.g.*before the meeting*), spatial (e.g. *on top of the house*) and abstract relations (e.g. *I did it for him*) between entities. Instead, these relations are mostly made clear using the signing space [6]. For example, when signing 'The boy walks to the cinema', the sign for 'walks' is performed from the locus of BOY in the direction of the locus of CINEMA. So what is actually being signed is BOY INDEX_{3a} CINEMA INDEX_{3b} $\text{WALK}_{3a,3b}$, where the direction of movement and orientation of WALK makes the use of a sign for 'to' unnecessary. Whilst most sign languages have signs for expressing temporal relationships, the signing space can also be used instead. In NGT in order to sign 'before the meeting', a so-called 'timeline' is used. The two-handed sign for MEETING is made and

then localised in the signing space by articulating INDEX with the non-dominant hand. The index finger of this hand remains at the locus of MEETING whilst the dominant hand moves from that location towards the signers body, indicating 'before'. Had the movement been made in the other direction, so away from the signer's body, then it would have meant 'after the meeting'.

As shown earlier in the example of WALK, in sign language a verb might need to be modified to suit the sentence. Such verbs that are adapted to suit the subject and object, or rather their loci, are known as agreeing verbs [6]. In the case of WALK its direction of movement and orientation are modified; in addition to the orientation of the sign, the start and end point of its movement indicate the subject and the object. Such verbs are known as directional verbs and allow the signer to identify the subject, verb and object of a sentence with one gesture. For example, if the signer performed the sign for 'help' moving away from themselves, this would mean 'I help you' ($\text{HELP}_{1,2}$). However, if they had performed the same sign in the opposite direction, towards the signer, it would be 'Help me' ($\text{HELP}_{2,1}$). Directional verbs are not limited to involving the signer and the interlocutor, though. If the signer placed BOB to their right and HOME to their left and subsequently signed WALK from right to left, they would be signing BOB INDEX_{3a} HOME INDEX_{3b} $\text{WALK}_{3a,3b}$. However, not all agreeing verbs are directional verbs, as the orientation alone of a verb can also show agreement. For instance, CALL ('roepen') has no path movement in NGT and only has a small repeated movement from the wrist. In this case the orientation of the sign decides the subject and object. The back of the hand indicates the caller and the fingertips point towards whom they are calling. In the examples mentioned, the signs move from subject to object and are orientated towards to the object. There are however also verbs were this is the other way around, such as the sign for INVITE in NGT. These verbs, whose target is the subject, are known as 'backwards verbs'.

2.3 Previous Research on Sign Language Translation and Synthesis

In the past two decades there has been increasing interest in the use of avatars for communicating in sign language [3] as a result of a desire to make public spaces and services more accessible to the Deaf community. Avatars have the great advantage of allowing for more flexibility, as the signs being displayed can be easily changed. Furthermore, when combined with machine translation, the avatars can also be used for (automatic) translation between sign language and text or even speech, making easier communication between hearing and Deaf people possible. For example, TESSA and her successor VANESSA were created in 2002 and 2004, to aid a Deaf person when they went to the post office, by translating the clerks speech into British Sign Language [24][25]. In another example, a system was developed that translated German train announcements into Swiss German Sign Language to be displayed on screens at train stations [26].

The use of sign language avatars is, however, not limited to the translation between spoken and sign language. PAULA is a computer-based sign language tutor that was originally created in 2006 to facilitate hearing adults in learning a limited vocabulary in American Sign Language (ASL) for use at the facility they all worked at [27] . The evaluation conducted with the staff on the use of PAULA showed that a sign language avatar can greatly improve the learning experience of hearing adults over other methods such as video's or even face to face lessons with a teacher. This is because the student can learn at their own pace and have the avatar repeat signs as little or as much as is necessary. It is also much easier for the student to go back to a specific sign, that they have difficulty with and just repeat that one. More recent research in Geneva in 2017 lead to a similar conclusion [28]. Based on this, a sign language avatar would be an accessible and effective method for hearing adults to learn how to speak sign language. This would be particularly of use in situations where it is essential for a hearing person to learn to speak sign language.

3 Global Methodology

The background on NGT and the previous research into using an avatar to translate and synthesise sign language in the previous chapter lead to the hypothesis that an effective system consists of three fundamental components:

1. software for sign language synthesis
2. lexical resources for encoding signs
3. grammatical resources for structuring sentences

The following sections discuss each of these components in detail.

3.1 Avatar Software

When it comes to synthesising sign language, two research groups have produced the most promising results: PAULA and Java Avatar Signing (JASigning) [27] [29]. However, as the research for PAULA is very specific to ASL, and not open source, this research will utilise the JASigning software.

In order to animate sign language using JASigning, the signs must be encoded in Signing Gesture Markup Language (SiGML), which is an XML application. SiGML is based on the Hamburg Notation System for Sign Languages (HamNoSys).

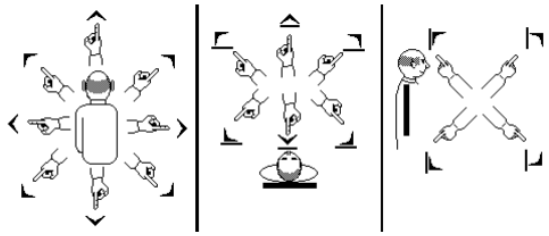
3.1.1 Hamburg Notation System

HamNoSys is an alphabetic system for transcribing signs using the five components handshape, orientation, location, movement and non-manuals, as described in sections 2.2.1, 2.2.2, 2.2.3, 2.2.4 and 2.2.5. An example of the HamNoSys notation for HOUSE can be seen in Figure 10.

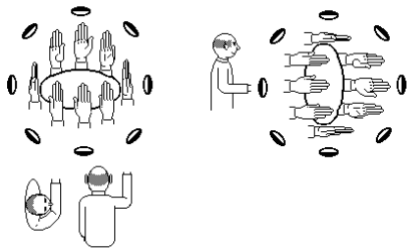
Figure 10: The HamNoSys Notation for HOUSE ([30])

Handshape[5] is determined by the general shape of the hand (e.g. fist or open) and the position and possible bending of the thumb. Additionally the position and possible bending of individual fingers can be specified (see Appendix A). Orientation describes the direction of the extended fingers[6] (or if they were to be extended) (see Figure 11a) and the direction of the palm [7] relative to them (see Figure 11b). The location consists of two components, the first determines where in relation to the body [8] and the second [9] determines at what distance from the body the sign is performed (see Appendix B). In the case of two-handed signs the location can also describe the relation of the two hands to each other. Actions describe in-place and path movements of hands [10], but can also describe for the non-manual component of the sign (see Figure 11c). It can also be specified whether the actions are performed sequentially or simultaneously. Two-handed signs are indicated by the symmetry symbol [11] at the start of the description [30].

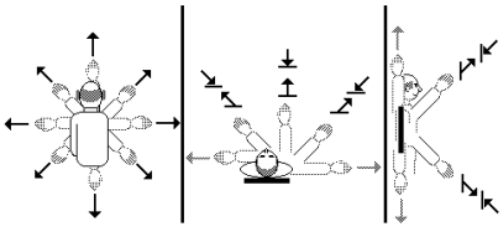
[5] The second symbol in Figure 10
[6] The third symbol in Figure 10
[7] The fourth symbol in Figure 10
[8] Omission signifies neutral space
[9] The fifth symbol in Figure 10
[10] The last two symbols in Figure 10
[11] The first symbol in Figure 10



(a) Finger Orientations in HamNoSys



(b) Palm Orientations in HamNoSys



(c) Movements in HamNoSys

Figure 11: Orientations and movements in HamNoSys ([30])

The HamNoSys notation of a single sign starts with a description of the initial posture, followed by the possible actions that are performed sequentially or simultaneously in order to change that posture. A posture consists of a description of the aforementioned phonemes in order, meaning that the initial handshape is first, followed by the orientation of the fingers and palm, followed by an optional body part and relative location to it, followed by an optional movement [30].

The great advantage of using HamNoSys, is that it does not rely on the conventions of a sign language, as these differ from country to country. This means that HamNoSys can be used to describe any sign language, which is why it is one of the most widely used transcription systems. A disadvantage of HamNoSys, however, is that it mainly focuses on the manual components of a sign. The nonmanual aspect is underdeveloped which means that the nonmanual components of a sign cannot be controlled to the same extent as the manual components. [30]

3.1.2 Signing Gesture Markup Language

Signing Gesture Markup Language (SiGML) is an XML based language used for "generation of sign language performances by a computer-generated virtual human, or avatar" ([31]).

There are two different types of SiGML: HamNoSys SiGML (H-SiGML) and gestural SiGML (G-SiGML). H-SiGML is based directly on HamNoSys, while G-SiGML is an extension of H-SiGML with more precise controls over the signing features. This project uses H-SiGML, as the database on which the corpus is based contains definitions of signs in this format. Listing 1 shows an example of SiGML code.

```
<?xml version="1.0" encoding="utf-8"?>
<sigml>

<hns_sign gloss="HUIS">
  <hamnosys_nonmanual>
    <hnm_mouthpicture picture='hYs'/>
  </hamnosys_nonmanual>
  <hamnosys_manual>
    <hamsymmlr/>
    <hamflathand/>
    <hamextfingerul/>
    <hampalmdr/>
    <hamparbegin/>
        <hamindexfinger/>
        <hamfingertip/>
        <hamplus/>
        <hamindexfinger/>
        <hamfingertip/>
    <hamparend/>
    <hamtouch/>
    <hamshouldertop/>
    <hamparbegin/>
        <hammovedr/>
        <hamsmallmod/>
        <hamarcu/>
        <hamreplace/>
        <hamextfingero/>
        <hampalml/>
    <hamparend/>
  </hamnosys_manual>
</hns_sign>

</sigml>
```

Listing 1: SiGML code for HOUSE

The start of a block of SiGML code is indicated by the notations in lines 1 and 2, and its end is indicated by the notation in line 33. Line 4 signals that the following lines encode the sign corresponding to the gloss. The nonmanual component is given in lines $5 - 7$, and in this case contains a mouth picture. The manual component is given in lines $7 - 30$. As explained in the previous section, line 9 denotes that the left hand must mirror the right and that this is therefore a two-handed sign. Lines 10, 11 and 12 define the handshape, finger orientation and palm orientation. Lines 14 - 18 and 23 - 28 describe the movements in the sign, as signalled by the notations on lines 13 and 22. In the second movement the hands first move down at an angle, shaping the roof of the house, and then the wrists rotate so that the fingers face forwards, shaping the walls. The first movement, however, does not actually describe a movement. It defines the touching in line 20 as only pertaining to the index fingers and not the whole hands. Line 21 simply states the location at which the sign should be made. Finally, the result of this code can be seen in Figure 12.

Figure 12: The sign HOUSE

3.1.3 JASigning

JASigning accepts either H- or G-SiGML as input, but internally converts the former into the latter (John Glauert, personal correspondence, May 28^{th} 2020). Moreover, JASigning has additional functionality, including control of the duration of a sign, an option for a non-manual to over-arch onto multiple signs, or the addition of pauses between signs [32, 26]. JASigning is accessible via a website or an applet [12]. The user interface (UI) provides several options, which include changing the signing speed of the avatar, displaying the sign frame by frame, and showing the gloss of a sign. An image of the JASigning UI is displayed in Appendix C.

3.2 Lexical Resources

In spoken languages, there is often not merely one single translation for a word from one language to another. The same issue arises when translating a spoken language to the sign language of that country. In sign languages, an extra layer of difficulty is added to a translation due to the use of classifiers (2.2.6). As a result, it is important to account for the fact that a word or concept should be represented in various ways in a lexicon. A system should be able to use the context of a word while computing its correct representation when multiple options are available (ideally due to parametrisation). If, on the other hand, there are no known representations of a word, the system should still have the ability to convey the message of the sentence. In real life, signers often either improvise or fingerspell the word. As fingerspelling is less ambiguous, it is desirable for the program to resort to this rather than improvisation — which would not be an efficient way to learn the language. Lastly, the program should be able to count correctly, as learning to do so is an important aspect of studying a new language.

[12] http://vhg.cmp.uea.ac.uk/tech/jas/vhg2020/index.html

3.3 Grammatical Resources

As mentioned in section 2.2, the signing space and non-manuals are essential for creating grammatically correct NGT sentences. Therefore, implementations of these two components are indispensable in a translator from glossed NGT to NGT. Through use of the signing space, sentences in NGT become much more comprehensible (see section 2.2.8). The addition of non-manuals[13] to gestures makes signs comprehensible, but also increases the naturalness of sign language (see section 2.2.5).

3.4 Overview Components

Figure 13 gives an overview of the expected final product and its components. This paper in particular will cover the implementation of the signing space. For an explanation of the implementations of the exical resources and the nonmanuals see [1] and [2].

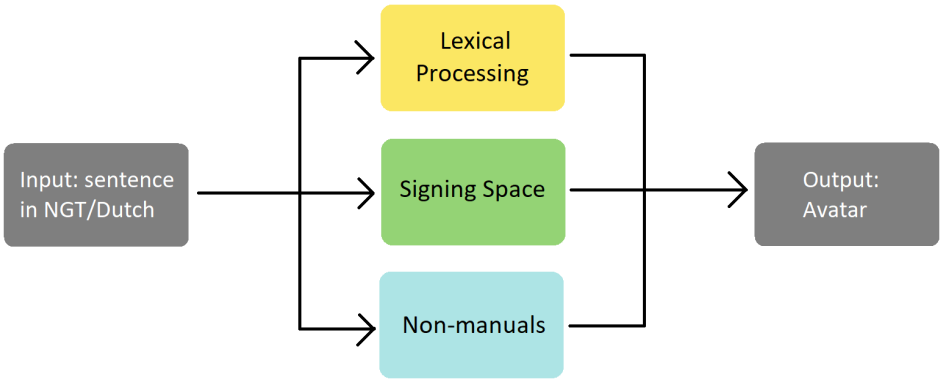


Figure 13: Outline Necessary Components

[13] Interesting to note is that previous research regarding sign language synthesis often neglects the implementation of non-manuals

4 Signing Space Methodology

This section will give an overview of the goals for the implementation of the signing space and the approach to realising these goals.

4.1 Goal

As mentioned in section 3.3, the signing space is an integral part of the grammar of NGT. It is not only used for references and keeping track of the conversation, but also for the agreement of verbs. The latter is the focus of this paper and therefore the implementation of indexing will be limited to use in that context. A proof of concept will allow a user to input a sentence in NGT containing a directional verb, with or without indices, which will then be signed by the avatar with indices and the verb modified to suit the object and subject of the sentence.

4.2 Approach

Two key components are necessary for an implementation of directional verbs: a process for assigning indices to nouns and directional verbs and a process for adapting the directional verbs on the basis of these indices. The following sections will give an idea of the scope of their implementations.

4.2.1 Indexing

In order for directional verbs to be able to adapt to the subject and object of a sentence, the latter must be translated into indices. As explained in section 2.2.8, pronouns can simply be directly translated to their INDEX equivalent. For nouns however, INDEX$_{3a}$ and INDEX$_{3b}$ should be assigned alternately, to ensure that one is assigned to the subject and the other to the object. However, the program should not simply assign INDEX$_{3a}$ to the first noun and INDEX$_{3b}$ to the second noun, as it should also be possible for users to construct sentences that already contain them. This means that if the user wants to translate the sentence 'She walks to him', the program should accept the sentence SHE HE WALK as well as the sentences INDEX$_{3a}$ INDEX$_{3b}$ WALK and INDEX$_{3b}$ INDEX$_{3a}$ WALK as valid input. In addition, the indices then also need to be assigned to the verb, so that the program knows which indices to adapt the directional verb to.

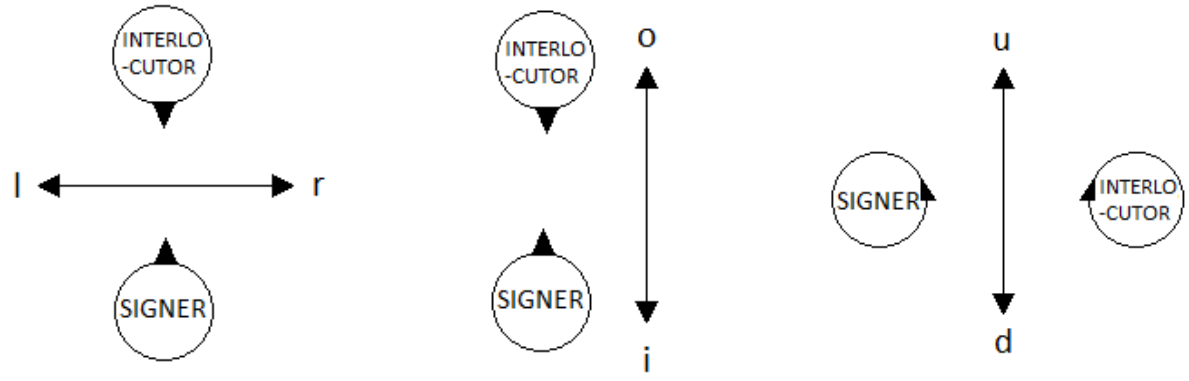
4.2.2 Adapting directional verbs

The next step is to change the direction of the movement and the orientation of the sign so that they suit the subject and object of the sentence.

```
11          <hamextfingerul/>
12          <hampalmdr/>
```

Listing 2: lines from the SiGML code for HOUSE

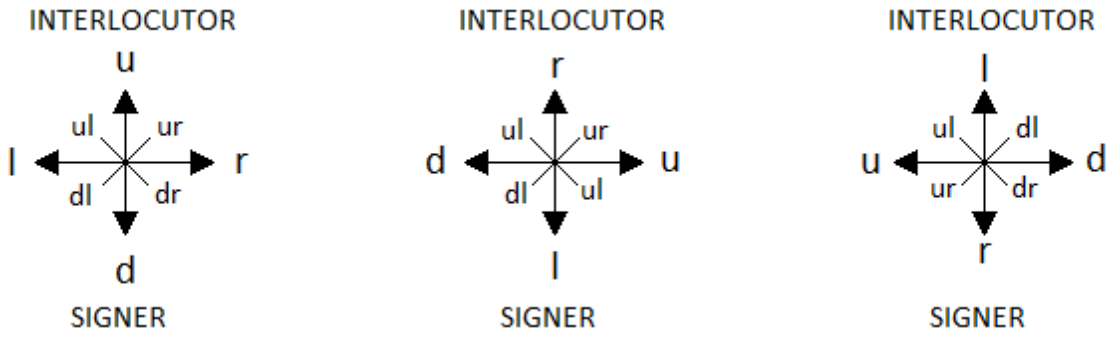
Lines 11 and 12 from Listing 1 show how finger and palm orientation are encoded in HamNoSys. The first parts of the notations on line 11 and 12, 'hamextfinger' and 'hampalm', signal that these are respectively describing finger and palm orientations. The orientations themselves are defined by the second parts of the notations: 'ul' and 'dr'.



(a) Left and right (top-down view) (b) Forwards and backwards (top-down view) (c) Up and down (sideways view)

Figure 14: The directions in HamNoSys

In HamNoSys there are six directions: u (up), d (down), r (to the right of the signer), l (to the left of the signer), i (towards the signer/backwards) and o (away from the signer /forwards), as can be seen in Figure 14. So line 11 and 12 from Listing 2 describe the fingers as orientated up and to the left and the palm as orientated down and to the right. However, as mentioned earlier, the palm orientation is relative to that of the fingers in HamNoSys, so the palm is not actually facing down and to the right. The palm's orientation can only be defined using the directions u, d, l and r, which is why the palm's orientation is relative to that of the fingers. When the fingers point straight upwards, the palm is no longer perpendicular to the body of the signer, but parallel. This means that the orientation of the palm is now defined as facing towards the signer (u) and away from the signer (d), with left (l) and right (r) retaining their meanings (see Figure 15a). Moreover, if the fingers are not pointing straight up, but are also tilted to the left or right, the meanings of the directions change again (see Figure 15b and Figure 15c). Similar changes occur when the fingers are pointing downwards and tilt to the left or right. However, signs are assumed to be encoded as when the subject of the sentence is INDEX_1 and the object is INDEX_2. This means that the new orientation can be determined based on the old one.



(a) palm orientations when fingers point straight up (b) palm orientations when fingers point up and to the left (c) palm orientations when fingers point up and to the right

Figure 15: palm orientations from the perspective of looking down on the signer and interlocutor

The start and end of a movement are signalled in HamNoSys by the words 'hamparbegin' [14] and 'hamparend' as can be seen in lines 22 and 26 of Listing 1:

```
22          <hamparbegin/>
23              <hammovedr/>
24              <hamsmallmod/>
25              <hamarcu/>
26              <hamreplace/>
27              <hamextfingero/>
28              <hampalml/>
29          <hamparend/>
```

Listing 3: line from the SiGML code for HOUSE

As mentioned in section 3.1.1, HamNoSys distinguishes between two types of movement: path and in-place. Line 23 of Listing 3 shows how a path movement is encoded in HamNoSys. As with finger and palm orientations, the first part of the notation, 'hammove', signals that this is a path movement and the second part 'dr' defines the direction of the movement as down and to the right. This means that just like with orientations, the new direction can be determined based on the old one. In-place movements are signalled by the word 'hamreplace', as can be seen in line 26. This signal word is then followed by new finger and/or palm orientations that replace the previous ones as can be seen in lines 27 and 28. These can be adapted by simply changing the finger and palm orientations as discussed. However, in some cases it might also be necessary to not just change the orientation and direction of movement of a sign, but also its start and end location. Lines 20 and 21 of Listing 1 show an example of how these are encoded in HamNoSys:

```
19          <hamparend/>
20          <hamtouch/>
21          <hamshouldertop/>
```

Listing 4: line from the SiGML code for HOUSE

As explained in section 3.1.1 a location can consist of two parts. The first part (line 20) specifies how close to or on what side of the body the sign should be made. The second part (line 21) specifies at which part of the body the sign should be made. As mentioned earlier, the signs are assumed to be encoded from the perspective of the subject being INDEX_1 and the object being INDEX_2. This means that the locations will need to be changed in sentences where the subject and object are different. In this case, however, the sign uses both hands, as specified by line 9 in Listing 1:

```
9           <hamsymmlr/>
```

Listing 5: line from the SiGML code for HOUSE

This means that the notation 'hamtouch' does not mean that the hands should touch the body, but rather that the hands should touch each other, as explained in section 3.1.1. In the case of two-handed signs, extra precaution should therefore be taken when changing locations.

[14] there are two other options that signal movement, but they are less common and will therefore not be discussed

5 Results and evaluation

The following sections contain the results and evaluations of the program as a whole (section 5.1.1 and section 5.2.1) and of the signing space component individually (section 5.1.2 and section 5.2.2).

5.1 Results

5.1.1 Global Results

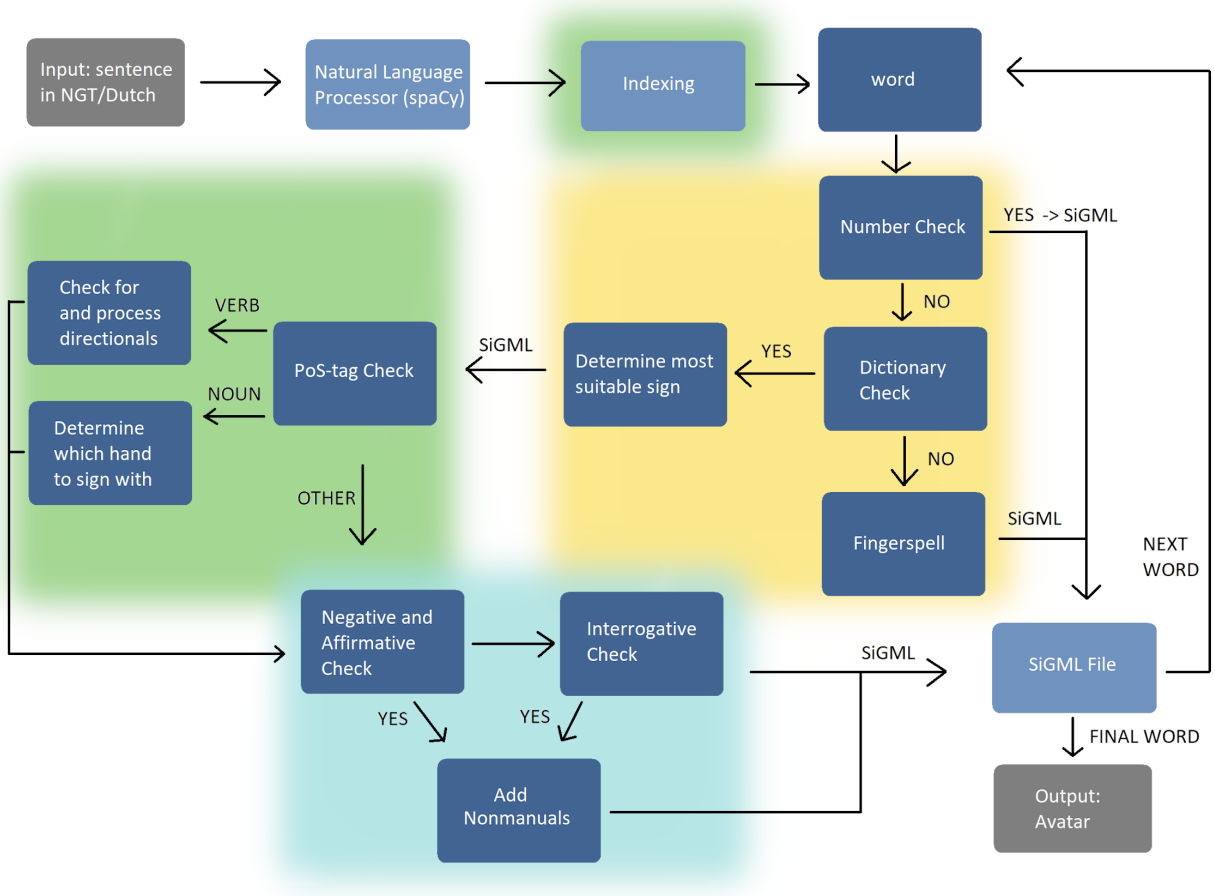


Figure 16: Pipeline of the entire program (the components part of lexical resources, the signing space, and non-manuals are indicated respectively by the yellow, green and light blue background squares)

The pipeline in Figure 16 shows the overall mechanism of the final system[15]. The program starts with an input sentence that can either be in NGT or an intermediate form of Dutch and NGT. It also accepts sentences in Dutch — as it produces signs in the order of the sentence — however, the output might not be in grammatically correct NGT. In addition, the program is not able to process multiple sentences at a time. Table 1 explains which input will produce correct versus incorrect output sentences.

[15]For instructions on how to install and use the program, see: https://github.com/LykeEsselink/SignLanguageSynthesis

Correct Input	Incorrect Input
MAN HUIS LOPEN MAN INDEX_{3A} HUIS INDEX_{3B} LOPEN	MAN HUIS LOOPT MAN NAAR HUIS LOPEN DE MAN HUIS LOPEN

Table 1: Examples of correct and incorrect input of the Dutch sentence 'De man loopt naar huis.' (The man walks home.).

The program consists of three main steps: pre-processing, translation of words into SiGML, and communication with the avatar. The first step of the program is the pre-processing of the sentence. SpaCy[16] is a natural language processor used to acquire the Part-of-Speech (PoS) tags and dependencies of the words in the sentence. In the case that the sentence is not in NGT, indices are added where necessary. The next step is completed for each individual word in the sentence. In order to ensure that the avatar knows which signs to produce, words are assessed on type. The program first checks whether the current word is a number and, if so, adds its SiGML to the file. Next, in the case that the word is not in the dictionary, it will be fingerspelled by the avatar, and otherwise an algorithm is applied to determine which sign in the dictionary is the most suitable to use and retrieves SiGML. After the corresponding sign has been chosen, the PoS-tag of the word is evaluated. If the word is a noun, the program checks with which hand to sign the word, and if the word is a verb, the program checks whether it is a directional verb and thus needs to be adapted. The final check determines whether the sentence is interrogative, negative, or affirmative, so that the appropriate non-manuals can be added to the sign. Once the word has been processed, the sign is added to a file which collects the SiGML of all the words in the sentence. Finally, after every word in the sentence has been processed, the file is sent to the avatar which then produces the signs in order.

5.1.2 Signing Space Results

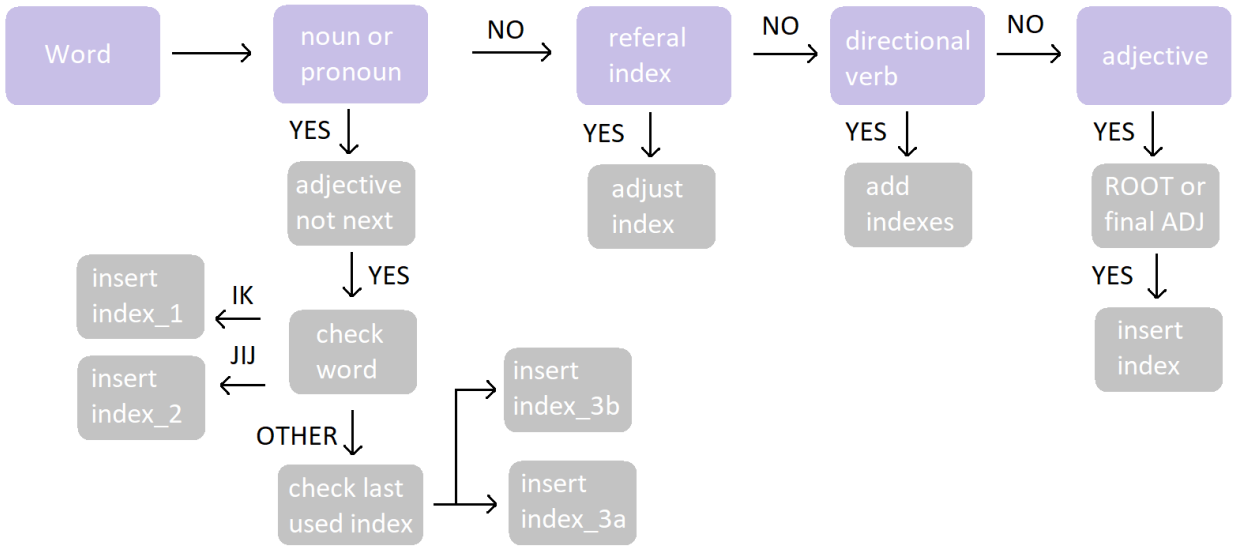


Figure 17: pipeline of indexing component

[16]https://spacy.io

Figure 17 shows an overview of how the implementation of indexing works. This component receives the words of the sentence with their PoS-tags and dependencies as input and then proceeds to process each word individually. If the word is a noun or a pronoun and the next word in the sentence is not an adjective, the corresponding index is inserted into the sentence. In the case of a noun or INDEX_{3a}, INDEX_{3b}, "he" or "she", the program checks whetherINDEX_{3a} or INDEX_{3b} was last used, to make sure that they are alternated in a sentence. In the case of a verb, the program checks whether it is also directional and if so, will add the indices of the subject and object to it. In the case of an adjective, the program checks whether it should insert the index of the corresponding noun. The user also has the option to input an index in order to be able to refer to a noun in a next sentence. These referal indices are treated differently to regular indices which simply replace pronouns.

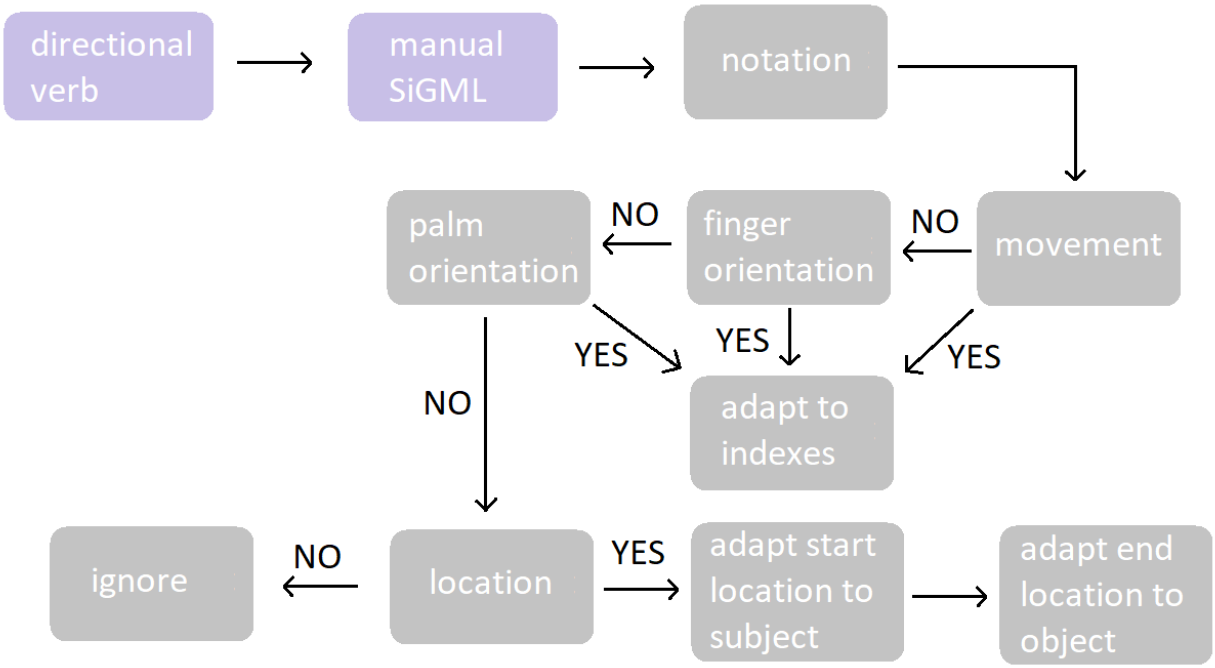


Figure 18: pipeline of the directional verbs component

Figure 18 gives an overview of the directional verbs component of the program. It receives a directional verb along with its assigned indices as input. It then retrieves the part of the SiGML code of the verb that describes the manual component of the sign and checks each notation in the code individually. If the notation describes a movement it will simply adapt its direction to suit the subject and object of a sentence. If the notation describes a finger orientation it performs several checks to determine whether to change it and how. First, it checks whether the fingers are facing up or down. If they are not, the program will simply calculate the new direction. Otherwise, it will check whether the fingers are pointing straight up or down, or are tilted. If the former is the case, the orientation stays the same and if the latter is the case, the new orientation is calculated taking into account which way the fingers are tilting. If the notation describes a palm orientation the program will ignore it if the palm is facing up or down and the fingers are not. However, if the fingers are pointing straight up or down, the palm orientation will be adapted, regardless of which way the palm is facing. In the other cases additional checks are performed to determine if and how to adapt the palm orientation. Finally, if the notation describes a location, the program will add fixed locations if the subject of the sentence is INDEX_{3a} or INDEX_{3b} and an arm extension if the subject is INDEX_2. It then determines based on the subject and object of the sentence, whether an end location is also necessary to add to the SiGML code.

5.2 Evaluation

5.2.1 Global Evaluation

In order to assess the overall performance of the program, eighteen test sentences (see appendix D) were constructed and given to the program to sign in NGT. The output of the program - the signing performed by the avatar - was recorded for each sentence and stored in a database along with its meaning. Two evaluators, one native speaker of NGT and one who learned it as an adult, were asked to watch the videos and fill out an evaluation form (Appendix E). The first step of the evaluation inquired them to interpret the meaning of the sentence based on the signing of the avatar. In the second step they were shown what the avatar was meant to sign, followed by various questions to assess the comprehensibility of the sentence and the naturalness of the signs.

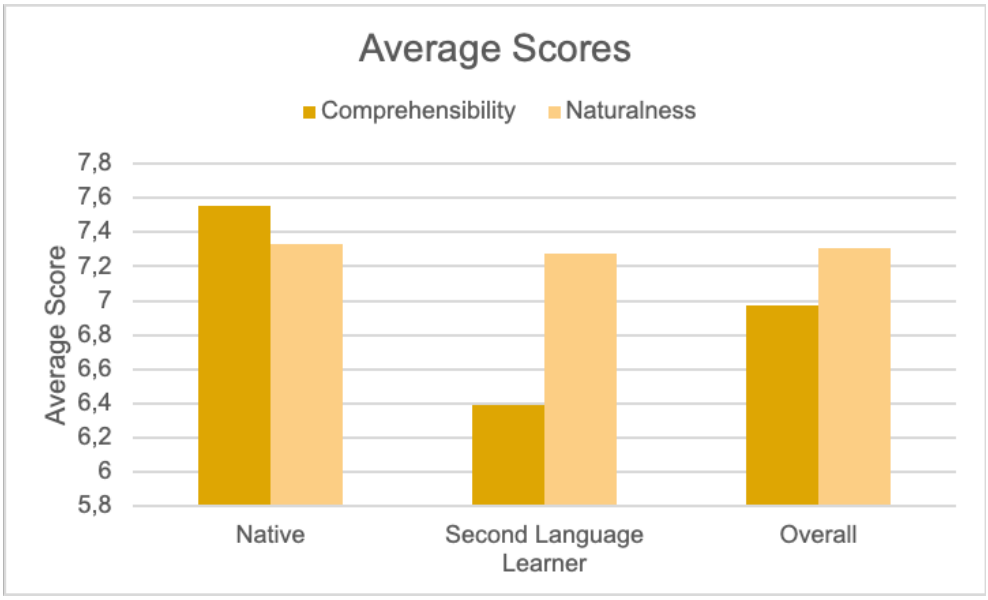


Figure 19: Average Scores of Comprehensibility and Naturalness

The evaluators were asked to score the comprehensibility and naturalness of each sentence on a scale from 1 to 10. Figure 19 shows the average results of the scoring [17]. Overall, the naturalness scores higher than the comprehensibility, with average scores of 6.97 and 7.31 respectively. Furthermore, the average scores given by the native speaker, 7.56 and 7.33, are slightly higher than the average scores given by the non-native speaker, 6.38 and 7.28, for respectively comprehensibility and naturalness. It is important to note that the feedback revealed that not all signs in the database are correct, which influenced the scores.

5.2.2 Individual Evaluation

As mentioned in the previous section, two speakers of NGT, one native and one none-native, were asked to evaluate the output of the program. Six of the sentences used in the evaluation pertained to indexing and/or directional verbs and can be found in Table 2. These sentences were created to test basic and non-basic sentences in order to best determine under what conditions the program succeeds and fails.

[17] Appendix F shows the overall results of the scoring.

Nr.	**NGT**	**Dutch**
1	MAN LANG OUD HUIS MOOI GROOT KIJKEN	De lange oude man kijkt naar het mooie grote huis
2	IK OUD MAN LOPEN	Oude ik loopt naar de man
3	JIJ INDEX_3A GEVEN	Jij geeft aan haar/hem
4	VROUW MOOI MANDARIJN HOUDEN VAN OP_AUX	De mooie vrouw houdt van de mandarijn
5	VROUW LANG OUD ZIJN VERDRIETIG	De lange oude vrouw is verdrietig
6	MEISJE MOOI LANG VROUW MOOI BANG	Een mooi lang meisje en een mooie bange vrouw

Table 2: Test sentences provided for evaluation

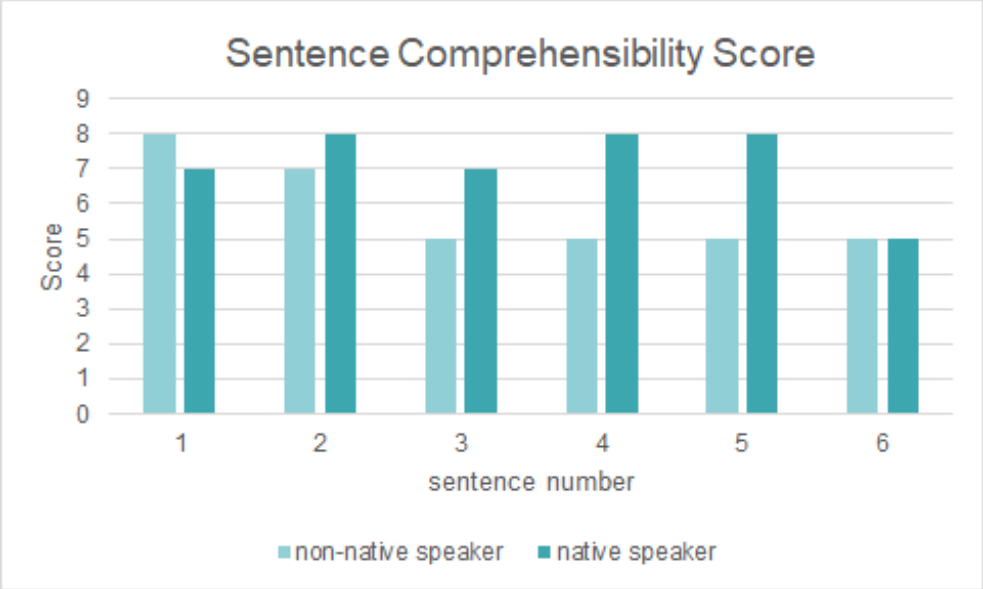


Figure 20: Comprehensibility Evaluation Indexing Sentences

Figure 20 shows the comprehensibility scores given to each sentence by each evaluator. Sentences 1 and 2 received similarly high scores from both evaluators, suggesting that they were easy to understand regardless of experience level with NGT. Sentence 6 received the exact same relatively low score from both evaluators. The native speaker gave the indexing being incorrect (it should be in between the noun and its adjectives, not after all the adjectives) as the reason for the low score. The non-native speaker had trouble understanding the sentence as it did not contain a verb. For sentences 4 and 5 both evaluators gave incorrect or incomplete signs as the reason for their scores. The relatively large discrepancy between their scores can perhaps be due to the native speaker also being a teacher of NGT and thus having more experience interpreting incorrect and incomplete signs. For sentence 3 the discrepancy between both scores is not as large, but still present. The non-native speaker was not able to recognise the sign GEVEN, as the sentence contained no object being given and the native speaker commented on INDEX_2 not being clear enough. Interesting to note is that most sentences are scored higher on comprehensibility by the native speaker than the non-native speaker.

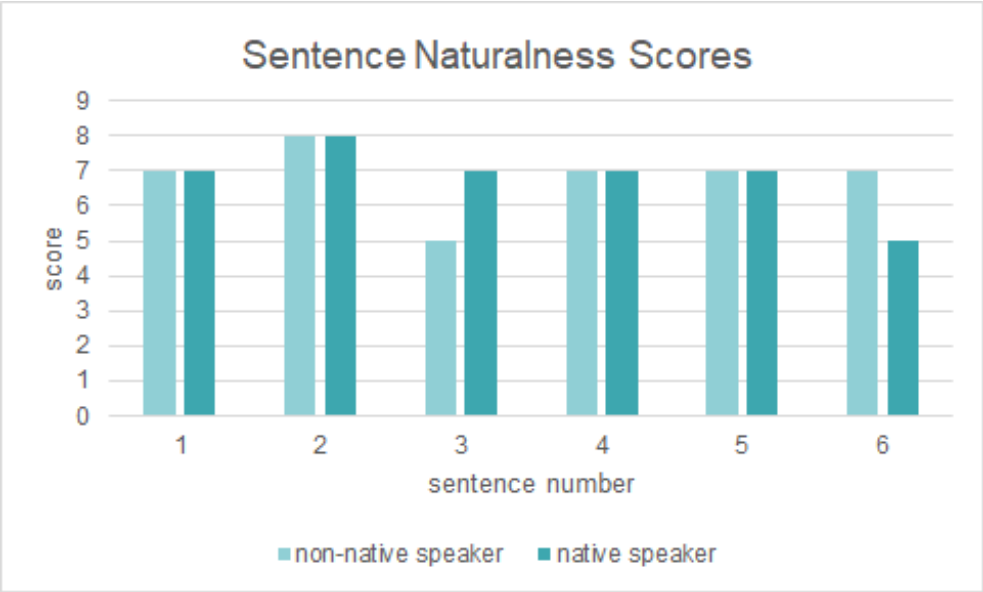


Figure 21: Naturalness Evaluation Indexing Sentences

Figure 21 shows the scores given for the naturalness of the signs in each sentence by each evaluator. For sentence 1 both evaluators noted that the gaze of the avatar should following along with the indexing to make it more natural. For sentence 2 there were no suggestions for improving naturalness, which is reflected in the relatively high scores of that sentence. As mentioned earlier, the non-native speaker had trouble understanding sentence 3, which most likely explains the relatively low naturalness score. Both evaluators commented on missing facial expressions for some adjectives from sentences 4 and 5, which decreased the naturalness of the signs. As previously mentioned, the native speaker remarked that the grammar of sentence 6 is incorrect, which also impacted the naturalness of the signs.

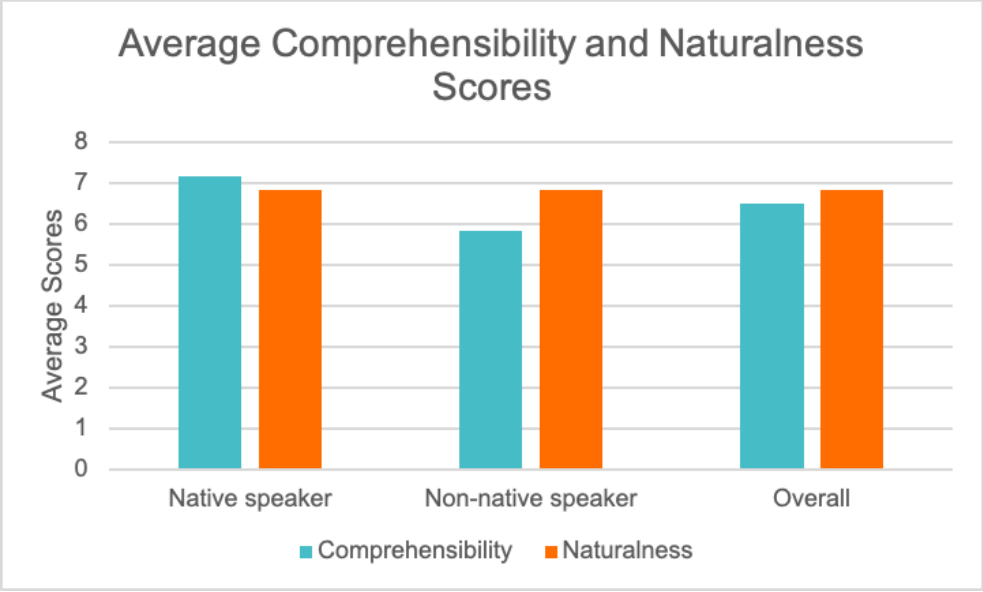


Figure 22: Average Comprehensibility and Naturalness Scores

Figure 22 shows the separate and combined average scores given by the evaluators for naturalness and comprehensibility. Interesting to note is that the average naturalness score is the same for both evaluators. As could be seen in Figure 21 the scores given by the evaluators only differed on two sentences. Comprehensibility was scored higher on average by the native than by the non-native speaker. The discrepancies in both categories are most likely caused by a difference in experience with interpreting NGT and/or a difference in comprehension of NGT.

Nr	**Dutch**	**Translation by native speaker**
1/9	Ik (loop/kijk) naar jou	INDEX_1 INDEX_2 $(\text{LOPEN/KIJKEN})_{12}$
2/10	Ik (loop/kijk) naar mijn buurman	INDEX_1 BUURMAN INDEX_3 $(\text{LOPEN/KIJKEN})_{13}$
3/11	Jij (loopt/kijkt) naar mij	INDEX_2 INDEX_1 $(\text{LOPEN/KIJKEN})_{21}$
4/12	Jij (loopt/kijkt) naar de leraar	INDEX_2 LERAAR INDEX_3 $(\text{LOPEN/KIJKEN})_{23}$
5/13	Het meisje (loopt/kijkt) naar mij	MEISJE INDEX_3 INDEX_1 $(\text{LOPEN/KIJKEN})_{31}$
6/14	De buurman (loopt/kijkt) naar jou	BUURMAN INDEX_3 INDEX_2 LOPEN_{32}
7/15	De vrouw (loopt/kijkt) naar de winkel	VROUW INDEX_{3a} WINKEL INDEX_{3b} $(\text{LOPEN/KIJKEN})_{3a3b}$
16	Ik gooi de bal naar jou	INDEX_1 INDEX_2 BAL GOOIEN_{12}
17	Ik gooi de bal naar de jongen	INDEX_1 JONGEN INDEX_3 BAL GOOIEN_{13}
18	Jij gooit de bal naar mij	INDEX_2 INDEX_1 GOOIEN_{21}
19	Jij gooit de bal naar het meisje	INDEX_2 MEISJE INDEX_3 BAL GOOIEN_{23}
20	De jongen gooit de bal naar mij	JONGEN INDEX_3 INDEX_1 BAL GOOIEN_{31}
21	De vrouw gooit de bal naar jou	VROUW INDEX_3 INDEX_2 BAL GOOIEN_{31}
22	De jongen gooit de bal naar het meisje	JONGEN INDEX_{3a} MEISJE INDEX_{3b} GOOIEN_{3a3b}

Table 3: Sentences signed by a native NGT speaker for comparison to the avatar (sentences 1 - 16 only differ on one word, indicated by the parentheses and the backslash)

In addition to an evaluation based on test sentences, an evaluation based on additional sample sentences signed by a native NGT speaker was also completed. The sample sentences and their Dutch translations can be found in Table 3. The nouns and pronouns in these sentences were replaced by their respective indices. The program was then asked to translate these sentences and the resulting verb was compared to the verb signed by the native speaker. The verbs were compared on direction of movement and orientation, the two most important components for adapting directional verbs. Figure 23 shows what the directional verbs look like when produced by the avatar.

(a) The end of the sign KIJKEN (b) The end of the sign LOPEN (c) The ending of the sign GOOIEN

Figure 23: The endings of signs used in the evaluation as produced by the avatar

Figure 24: The number of times that the direction of the movement of the verb signed by the native speaker and of the verb signed by the avatar matched

Figure 24 shows the number of sentences where the direction of the movement of the verbs signed by the native speaker and by the avatar were the same. The movement is always correct in the case of the verb GOOIEN (throw), but KIJKEN (look) en LOPEN (walk) were both incorrect the same number of times. In the case of LOPEN and KIJKEN this is most likely caused by the fact that the target location of the signs is different for the native speaker than for the avatar. This suggests that even though location does not play a large role when signers adapt directional verbs, it should be taken into account when synthesising sign language.

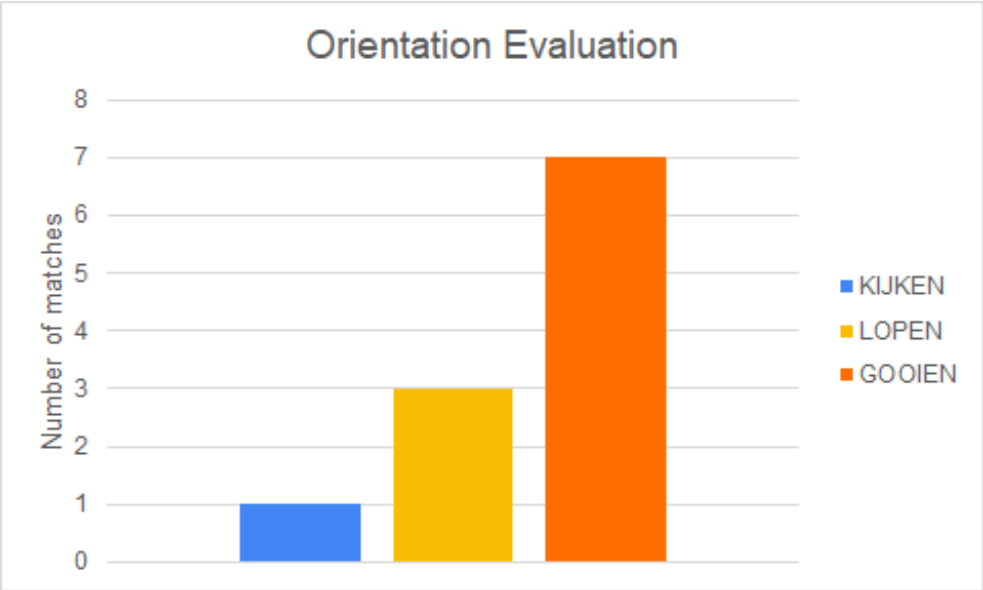


Figure 25: The number of times that the orientation of the verb signed by the native speaker and of the verb signed by the avatar matched

Figure 24 shows the number of sentences where the orientation of the verbs signed by the native speaker and by the avatar were the same. The orientation only matches once in the case of KIJKEN, which is when the subject of the sentence is INDEX_1 and the object of the sentence is INDEX_2. This is because the program assumes that the orientation of the sign is always the same relatively to the subject and object. However, in the case of KIJKEN, the palm and fingers only face the subject of the sentence if the subject is INDEX_1 as in Figure 23a, and face the object in all other cases. In the case of LOPEN the orientation only matches three out of seven times. The handshape of LOPEN causes the native speaker to adapt the orientation differently than in the cases of other directional verbs, in order to be able to comfortably sign. The avatar always keeps the palm facing down, as in Figure 23b, which would be painful to do for a person signing in real life. The avatar is not restricted in the same way and thus adapts the signs orientation as it would in any other case, leading to signs that would be painful. As with the direction of movement, in the case of GOOIEN the orientation of the sign always matches that of the native speaker. This suggests that GOOIEN is an easy sign to adapt for both people and avatars, as the handshape (as can be seen in Figure 23c) does not cause restrictions.

6 Conclusion and Discussion

6.1 Conclusion

The results show that the directional verbs component performs well on average. Both the native and the non-native speaker gave relatively high scores for naturalness and good scores for comprehensibility. Overall, based on the feedback given by the evaluators, it is clear that the directional verbs themselves work, but that other components of the program, such as the signs themselves, need to be improved. Furthermore, the adaptation of directional verbs by the avatar is promising, but should take more exceptions into account, such as when the orientation is changed differently in order to make the sign comfortable for a human to produce. It should also be noted that the number of sentences used for testing was small and the sentences varied greatly. This means that additional testing would need to be done for a complete and fair overview of what specifically needs to be improved upon.

6.2 Discussion

This research does not provide a comprehensive implementation for directional verbs. The original idea was to create a general implementation, but during the research this turned out to be too complex. HamNoSys only allows for descriptions of signs in absolutes, meaning that it is not possible to simply rotate a sign. The orientations and movements have to be individually adjusted, which results in a number of special cases that require separate approaches. Due to this limitation the implementation only works for a limited amount of directional verbs. The implementation also assumes the object of a sentence to be the target of a directional verb, which means it does not work for backwards verbs. In order to make this implementation more comprehensive, more research would need to be done into how exactly every directional verb in NGT needs to be adapted in HamNoSys.

The indexing component was implemented as it was necessary for directional verbs and is therefore quite limited. When it comes to assigning indices to nouns and translating words into indices, it works perfectly. However, the evaluation made it clear that the nonmanual components of indexing need to be improved upon to make it seem more natural and increase its comprehensibility. As an addition, the indexing was expanded to work in conjunction with adjectives. However, as was noted in the evaluation, this part of the implementation does not always work correctly. More research into how indices behave with adjectives and in interrogative sentences could greatly expand its capabilities [33].

6.3 Future Work

The program overall has most of the basic functionalities, but needs to be expanded before it can be used as a tool for learning NGT. Firstly, the program cannot actually translate sentences from Dutch to NGT. It uses a natural language processor to gain syntactic information necessary for producing NGT, but the processor works based on Dutch. This means that NGT sentences are not always processed correctly, resulting in unnecessary errors in the NGT sentence. Secondly, the evaluation made it clear that not all of the signs in the database are correct or clear. Improving the signs and adding missing facial expressions will greatly improve the naturalness and comprehensibility of the sentences signed by the avatar. Furthermore, the implementation cannot process non-agreeing verbs correctly, which result in grammatically incorrect translation of sentences. A large number of verbs are non-agreeing in NGT, so being able to correctly process them would drastically increase the usability of this program. Lastly, the program can only process one sentence at a time, meaning that a user cannot input multiple sentences to form a story. This capability may not be useful to a beginner learning NGT, but a more advanced learner would greatly benefit from being able to provide more context to their translation.

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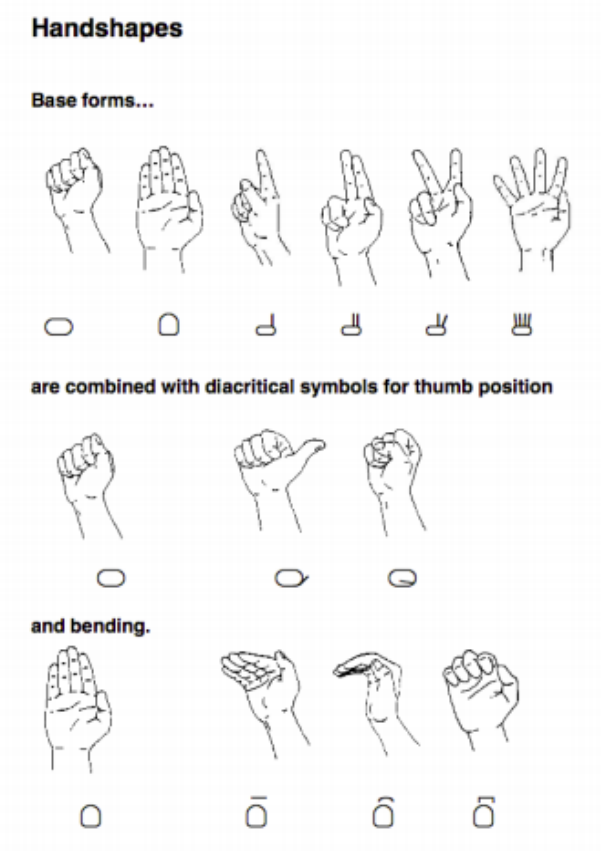
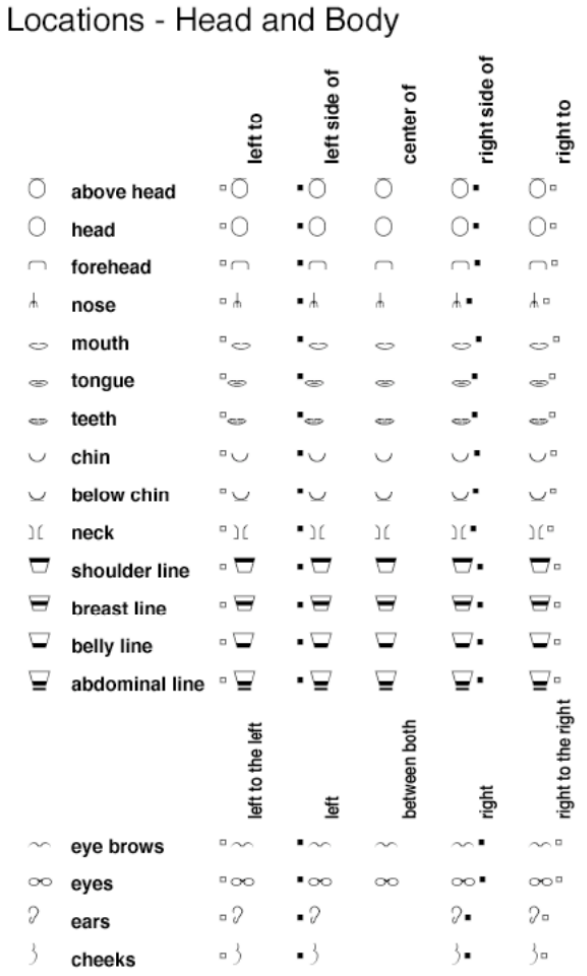
A Hamnosys Handshapes



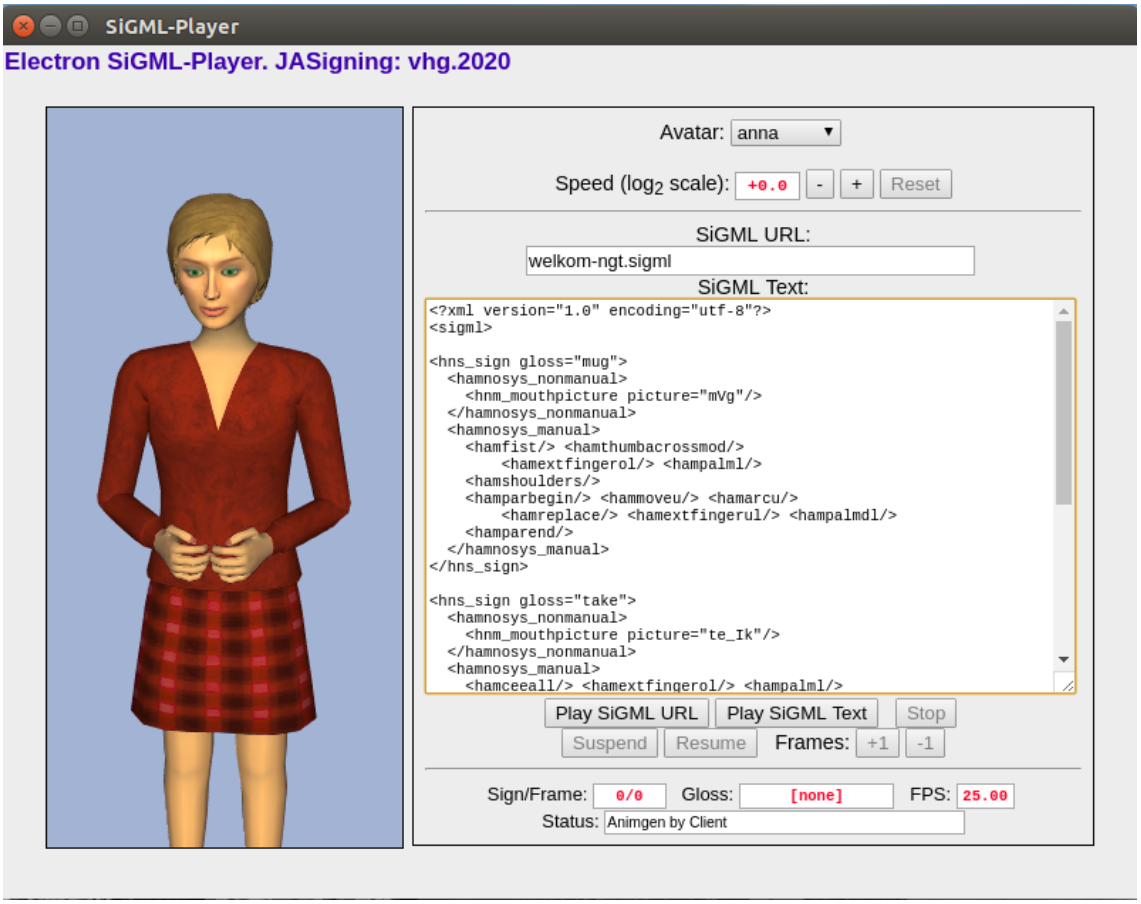
[30]

B HamNoSys Locations



[30]

C JASigning User Interface



D Evaluation Sentences

	NGT	Dutch
Lexical Resources	MAN 33 PLANT KOPEN	De man koopt 33 planten
	VANAVOND KIND WIL SNOEPJES ETEN	Het kind wilt vanavond snoepjes eten
	PAARD HOUDEN-VAN SPRINGEN	Het paard houdt van springen
	MEISJE TENTAMEN WILLEN HALEN	Het meisje wilt het tentamen graag halen
	JONGEN BOOS BRUG OPEN	De jongen is boos want de brug staat open
	KASTEEL 3571 JAAR OUD	Het kasteel is 3571 jaar oud
Directional Verbs and Indexing	MAN LANG OUD HUIS MOOI GROOT KIJKEN	De lange oude man kijkt naar het mooie grote huis
	IK OUD MAN LOPEN	Oude ik loopt naar de man
	JIJ INDEX_3A GEVEN	Jij geeft aan haar/hem
	VROUW MOOI MANDARIJN HOUDEN VAN OP_AUX	De mooie vrouw houdt van de mandarijn
	VROUW LANG OUD ZIJN VERDRIETIG	De lange oude vrouw is verdrietig
	MEISJE MOOI LANG VROUW MOOI BANG	Een mooi lang meisje en een mooie bange vrouw
Non-manuals	OUD-EN-NIEUW OLIEBOL ETEN WIE?	Wie eet een oliebol op oud-en-nieuw?
	VRACHTWAGEN BOTSEN WAAROM?	Waarom botste de vrachtwagen?
	NEEF NACHTMERRIE HEBBEN?	Heeft de neef een nachtmerrie?
	JIJ 3 OF MEER DOCHTER HEBBEN?	Heb jij 3 of meer dochters?
	KEIZER LOPEN OF RENNEN?	Loopt de keizer of rent de keizer?
	BOER NOOIT MELK VIES OF NOOIT EI VIES	Heeft de boer nooit vieze melk, of nooit vieze eieren?

Table 4: Test sentences provided for evaluation

E Evaluation Form

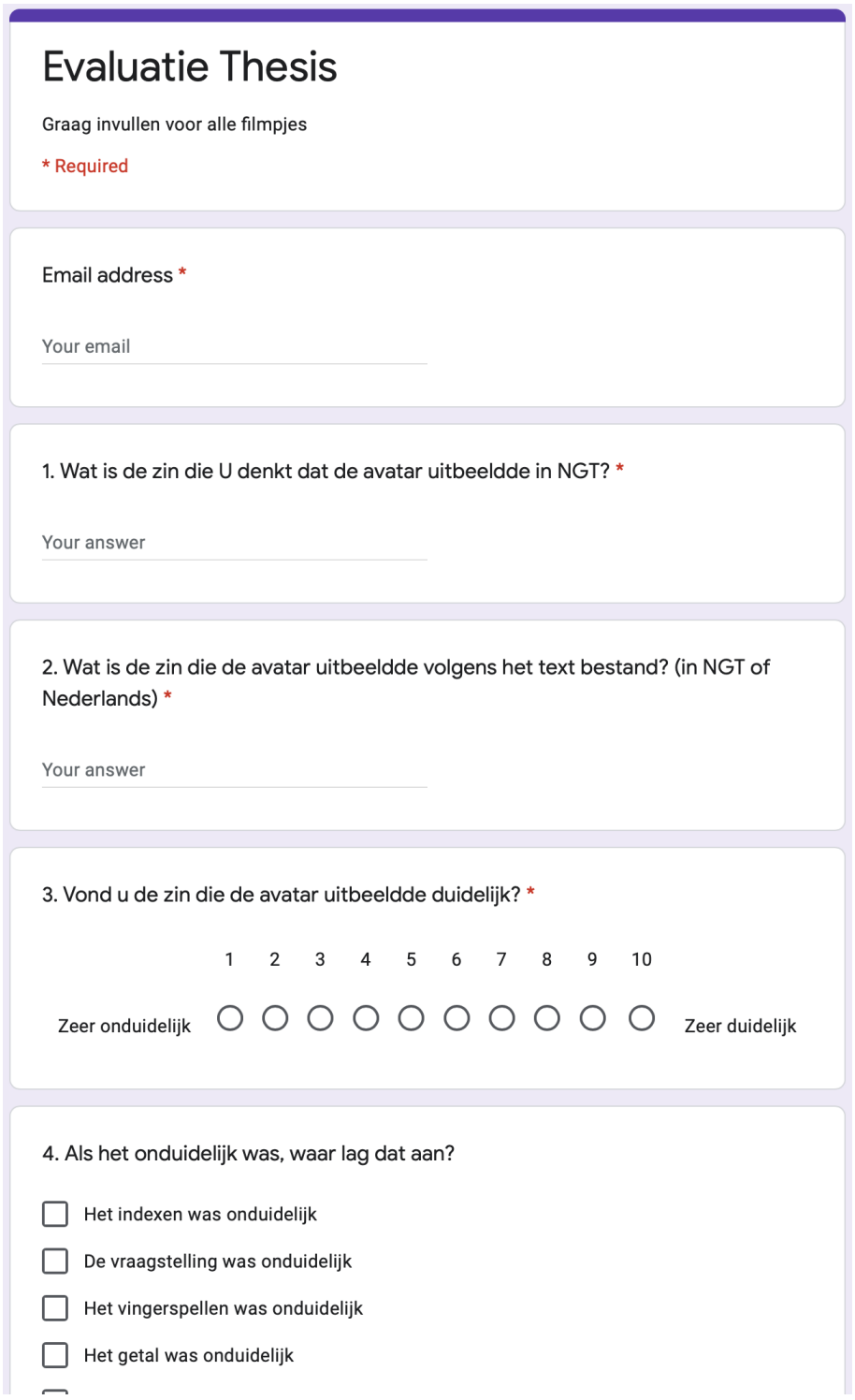


Figure 26: Evaluation Form

Figure 27: Evaluation Form

F Global Results

Two Figures showing the grades of comprehensibility and naturalness of the avatar.[18]

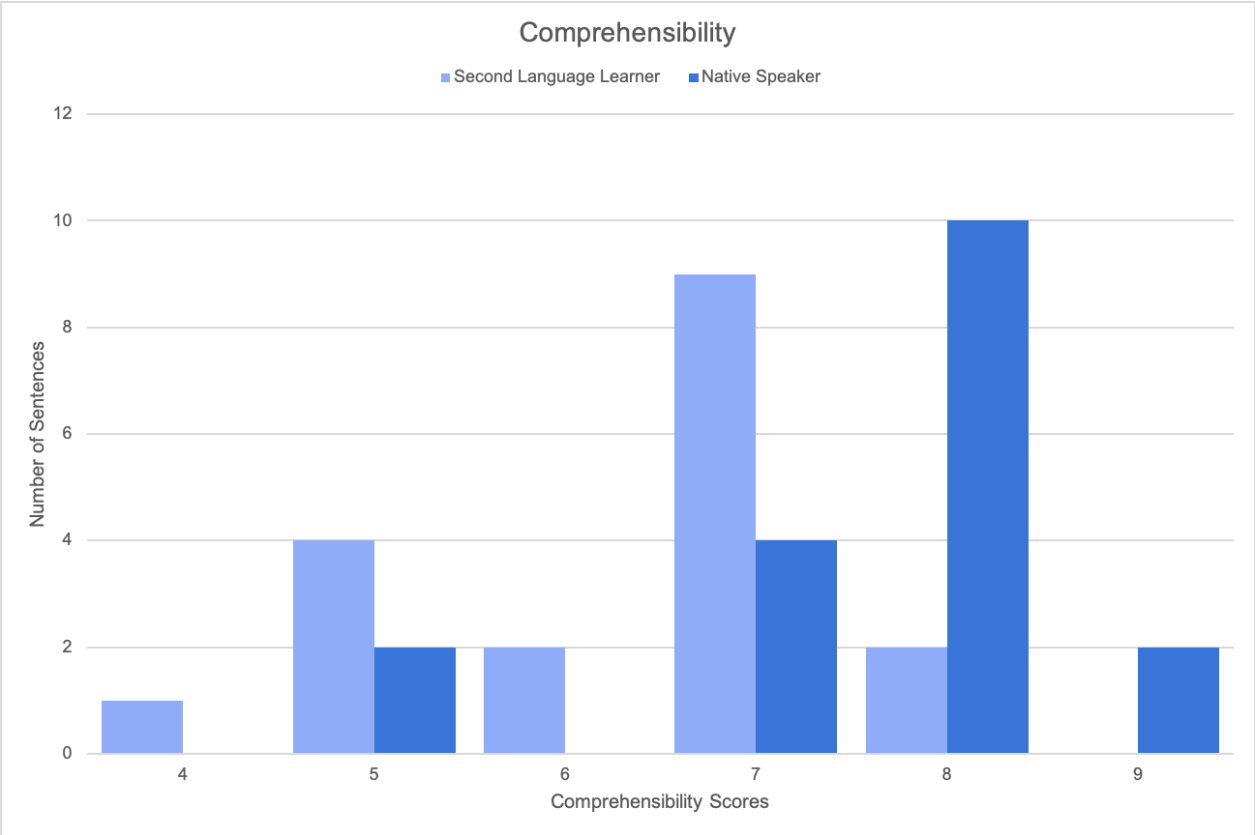


Figure 28: Comprehensibility (Average Score of 6.97)

[18]Scores that were never chosen by the evaluators are not shown.

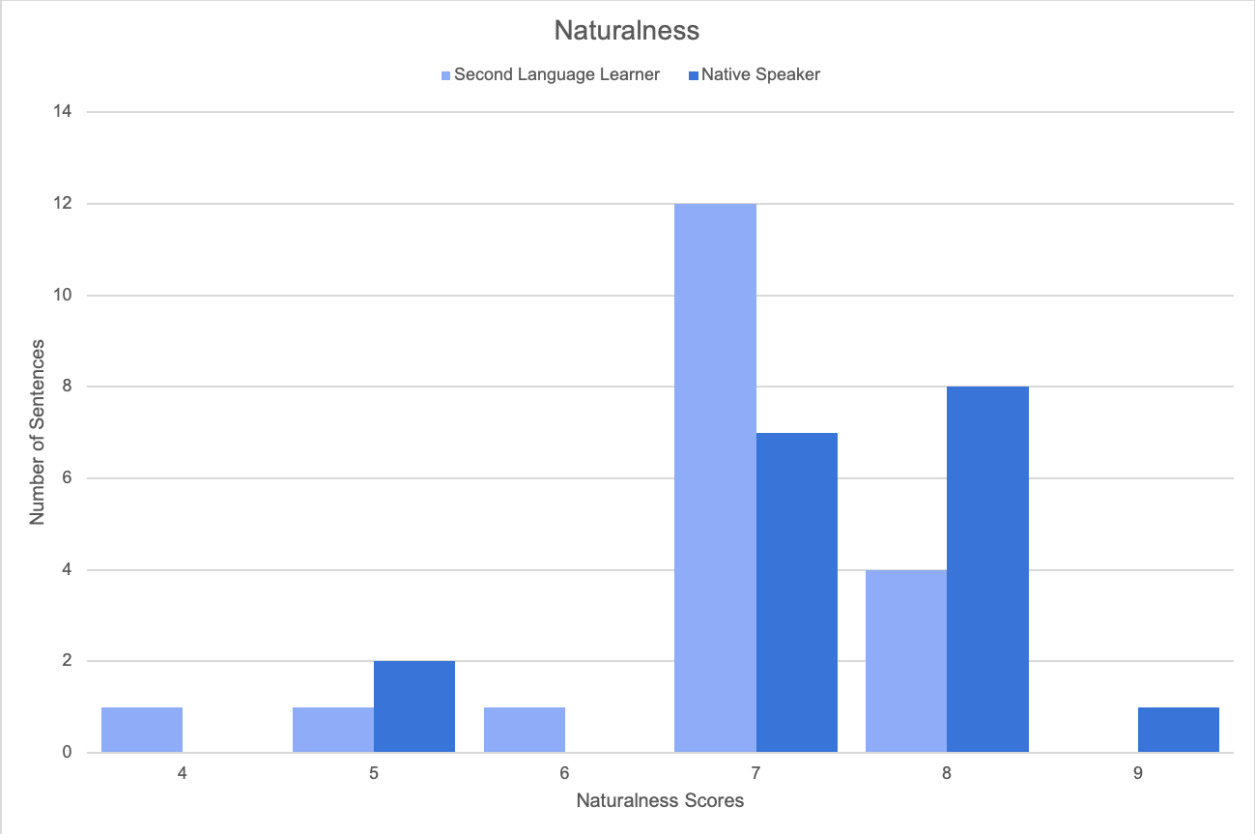


Figure 29: Naturalness (Average Score of 7.31)