e-LIS

Electronic Bilingual Dictionary
of Italian Sign Language–Italian

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written by

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To Jay Anderson

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Abstract

Sign languages are visual languages used in deaf communities, mainly. They simultaneously combine shapes, orientations and movements of the hands, as well as non-manual components, e.g., facial expressions. Their spatial nature makes it difficult to write or even transcribe them. Moreover there is not a one-to-one relation between a sign language and the related verbal language; a word may be represented by more than one sign; likewise, one sign may be translated into more than one word. For instance, there is a single sign in Italian for the "cut with scissors" expression (see 383.1 in [15]). This makes the creation of a sign language dictionary quite a challenging one.

The e-LIS project, for which we worked, aims at the creation of the first Electronic bidirectional dictionary for Italian Sign Language – Italian (Verbal Language). The creation of the e-LIS dictionary requires a combination of expertise and skills from various fields. In this thesis, we focus on the creation of an ontology for e-LIS, here conceived as a means for *analysing*, *representing* and *reasoning* with the entities and relations of the sign language dictionary.

The enriched knowledge provided by the e-LIS ontology will guide users when they look up in the e-LIS dictionary for a specific sign; in particular users who are not familiar with Italian sign language or the transcription systems should benefit from the expert navigation provided by our ontology. Moreover, our ontology can be integrated with the SEWASIE query tool, which allows for the automated extraction of signs from the dictionary database.

This thesis concludes with several open questions at the intersection of knowledge representation and reasoning, sign and computational linguistics, human computer interaction, data base design, internet technologies, which most elicited our research interests.

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Chapter 1

Introduction

1.1 Who can benefit from this thesis

Two main research fields converge in this thesis: that of Italian sign language, namely a visual language based on body gestures used in deaf communities, mainly; that of knowledge representation and reasoning, more precisely, with ontologies.

As they are rather separate communities, this thesis presumes no knowledge of sign languages or ontologies, and it is meant to speak to both communities.

1.2 Thesis structure

The material of this thesis is divided in four main chapters, outlined as follows.

Chapter 2 provides an introduction to sign languages, focusing on Italian sign language and its relation to Italian verbal language. It gives an overview of transcription systems and the ordering principles of [15], an Italian sign language dictionary from which our work stems.

The e-LIS project, which aims at the creation of a bidrectional dictionary for Italian sign language–Italian verbal language in electronic format, is briefly outlined in Chapter 3.

Chapter 4 is the kernel of this thesis. First it describes what an ontology is and its practical applications. Then it focuses on the e-LIS ontology, describing the whole ontology, its developing strategy, its roles within the e-LIS project and the tools we used to create the ontology. Concluding the chapter is a small test of the query tool of SEWASIE with our e-LIS ontology as input.

Chapter 5 concludes the thesis; there we discuss the goals, achievements and the remaining issues of our work.

Given its physical size, our e-LIS ontology did not fit in this thesis. However it can be freely downloaded from the e-LIS web page [5].

Chapter 2

Background

Myths and biases about sign languages persist nowadays. This chapter provides some background information on sign languages, restricted to what is necessary to understand the matters of this thesis. Section 2.1 is an introduction to sign languages; it focuses on Italian sign language and its relations to Italian verbal language. An overview of transcription systems for Italian sign language, limited to those of interest to our work, is given in Section 2.2. The last section of this chapter, Section 2.3, overviews the LIS dictionary on which our thesis work is based.

2.1 Sign languages

A *Sign Language* (SL) is a visual language based on body gestures instead of sound to convey meaning. It simultaneously combines shapes, orientations and movements of the hands, as well as non-manual components, e.g., facial expressions. SL's are not pantomime, nor are they a visual rendition of the related *Verbal Language* (VL). They have rich, complex spatial grammars of their own, e.g.: a sign can involve one hand (the so-called *dominant hand*) or both hands; these can be symmetrically placed or not. SL's can be used to discuss any topic, from the simple and concrete to the lofty and abstract [20].

Wherever communities of deaf people exist, SL's develop. Deaf communities can include interpreters, friends and families of deaf people as well as people who are deaf or hearing-impaired themselves. Therefore, contrary to popular belief, SL is *not universal*; SL's vary from nation to nation; even more, SL's such as *Italian Sign Language* (LIS) have dialects of their own.

Their spatial nature makes writing or even transcribing SL's a challenging and complex task; in Section 2.2 below we briefly elaborate on this. Moreover there is not a one-to-one relation between an SL and the related VL. A VL word may be represented by more than one SL sign. Likewise, one sign may be translated into more than one word, such as the sign for "cut with scissors" (see 383.1 in [15]). This makes the creation of a bidirectional dictionary from Italian VL to LIS, and vice-versa, quite a challenging one; we focus on this in Section 2.3 below.

2.2 Sign language transcription systems

The current interest on transcription systems for SL's can be traced back to the study of American SL (ASL) pioneered by Stokoe in 1960. However nowadays efficient, widely standardized notation/transcription tools for representing SL's [14] are still missing.

According to [7], transcription systems can be classified into two main types: (1) autonomous systems, i.e., systems of notation based on rules and on particular modes of representation requiring no knowledge of another written form (e.g., Stokoe, 1960; HamNoSys, 1989); (2) notation systems employing as medium of representation a pre-existing written form, namely, that of the national VL, e.g., see the Ph.D. thesis by Cuxac, 1996.

In the remainder we focus on transcription systems of type (1) which are of interest to our work, thus leaving out other richer yet more complex writing systems such as SignWriting (V. Sutton, 1974).

Stokoe

The Stokoe system for American sign language (ASL) was the first transcription system for a sign language. The system was published in 1960 and was used to organize the entries of *A Dictionary of American Sign Language on Linguistic Principles*, written by Stokoe with two deaf colleagues of Gaulladet University [18].

His system uses elements of the Latin alphabet and is phonemic, with a reduced set of symbols rather than attempting to capture all signs. For instance, there is a single symbol for circling movements, regardless of whether the plane of the movement is horizontal or vertical. The transcription of a sign is then linearly arranged on the page. The original notation consisted of 55 symbols divided into three categories, namely: location, handshape, movement/orientation. This distinction resembles that of VL's into consonants, vowels and tone.

The location and movement symbols are iconic, while handshape is represented by units taken from the number system and manual alphabet of ASL [9].

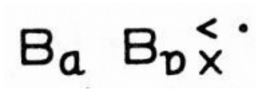

Figure 2.1: *Newspaper* in Stokoe notation for ASL, taken from [18].

HamNoSys

HamNoSys was developed by a group of hearing and deaf people as a research tool and first made publicly available in 1989. It was designed to fit a research setting and should be applicable to every sign language in the world. It consists of about 200 iconic symbols covering the categories of handshape, hand configuration, location and movement. It is possible to note down facial expressions.

The order of the symbols within a string is fixed, but still it is possible to write down one and the same sign in lots of different ways. The transcriptions are very precise, but also very long and cumbersome to decipher. For instance, compare Figures 2.1 and 2.2.

HamNoSys is still being improved and extended all the time as the need arises. The system is used, for example, in research institutions in Finland, Australia, New Zealand, Switzerland and Germany [2].

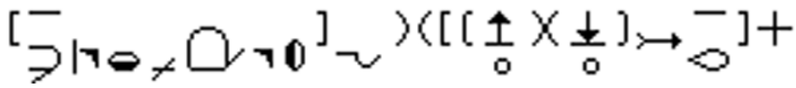

Figure 2.2: *Newspaper* in HamNoSys for ASL, taken from [2].

2.3 LIS dictionary

The LIS dictionary [15] by Radutzky is a dictionary from LIS to Italian VL. It accounts for about 2500 signs.

The transcription system of LIS adopted in [15] is an extended and modified version of the Stokoe-transcription system mentioned above; for instance, it adds the initial position of hand/hands as category. Non-manual features of LIS were not included in [15]; they involve facial expressions, movements of the head, shoulders and trunk.

A sign is a sequence of terms from the four categories of [15]; we briefly describe them as below. Changing one of those terms results in a different meaning of the sign or sometimes meaningless gestures.

2.3.1 The transcription system of the dictionary

Handshape

Handshape is the shape the hand/hands takes/take while signing. This is the most complex category as it alone counts more than 50 terms in LIS. Each handshape is represented via an extended alphabet symbol in [15].

Initial position of the hands

The *Initial position of the hands* category is divided in: orientation of palms, that is how the palm is directed in relation to the body at the initial position (e.g., palm up); how the hands are arranged in relation to each other at the initial position (right hand above left hand); hand or finger contact with a body at the initial position.

Location of the hands

The *Location of the hands* category expresses the articulation place, namely, the position of the hands (e.g., on your forehead, in the air).

Movement of the hands

The *Movement of the hands* category can be divided in: movement of the hands or fingers (e.g., cyclic); direction of the movement (e.g., upward, downward, backward, forward or diagonally); relational hand movement (e.g., inserting one hand into the other as a result of the movement, approaching hands); touch.

2.3.2 Ordering principle behind the dictionary

In [15], sign transcriptions are ordered as follows:

C1. handshape,

C2. palm orientation/initial position,

C3. location,

C4. movement.

The handshape category is further subdivided and ordered in eleven categories; for instance, the *flat handshape* category occurs as first among all the eleven handshape categories, as flat handshapes are the most frequent in LIS signs. According to [15], such ordering choice is the result of a “logical progression” — not further specified in [15].

Therefore, in order to look up in [15] for a sign, the user should: first decompose it in its C1–C4 components; then browse the dictionary following the order given by the list annexed at the end of the dictionary, and sketched above. In this manner, searching for a sign in the dictionary requires some knowledge of LIS, which makes its consultation more demanding for LIS unexperienced users.

Chapter 3

The e-LIS project

This chapter overviews the e-LIS project. Section 3.1 describes the main aims of the e-LIS project, its team and the current state of work. Section 3.2 explains our role in the project.

3.1 The e-LIS project and team

E-LIS is a research project lead by the European Academy of Bozen-Bolzano (EURAC). Main partners of the project are the ALBA deaf cooperative of Turin and the Free University of Bozen-Bolzano (FUB).

The project aims at the creation of the first electronic bilingual dictionary of Italian Sign Language–Italian; the former is referred to as LIS (*Lingua Italiana dei Segni*). The e-LIS dictionary employs the same Stokoe-based transcription system adopted in the paper dictionary by Radutzky [15], which is described in Section 2.3 above.

The electronic format is particularly suited to a spatial language such as LIS; for instance, it allows for videos to be integrated in the dictionary and used to display signs. As the dictionary aims at reaching as many users as possible, developing the dictionary as a web application is the natural choice.

Stokoe-based notations, as those adopted in [15], can be used for notating single de-contextualized signs, as in most SL dictionaries. However, as remarked in [14], currently there are no dictionaries or reference grammars that rely on this notation as the primary means for representing the SL signs they describe; the notation is always integrated with text descriptions in the related VL. On the contrary, the e-LIS dictionary aims at describing and contextualising signs using LIS as the meta-language — like in standard monolingual dictionaries for Verbal Languages (VL's).

In this perspective, it also aims at offering a search engine that allows the user to directly search for a sign, without resorting to the corresponding Italian term(s).

Such an ambitious goal calls for: a navigation system for guiding even non-expert users; a powerful search-engine enabling intelligent retrieval of signs. This demands a mix of expertise and skills from various fields such as: computational linguistics, knowledge representation and reasoning, human computer interaction, database design, Internet technologies.

3.2 Our role in the project

The main contribution of this thesis to the project is the e-LIS ontology for the web navigation system and the search engine.

When FUB entered as partner in the team, the development phase of e-LIS was already in progress, and some decisions were already taken, for instance, the sign transcription system of Radutzky [15]. This is also why our e-LIS ontology is based on it.

We discuss our ontology and its uses for the e-LIS dictionary in the following chapter.

Chapter 4

The e-LIS ontology

This is the core chapter of the thesis.

Section 4.1 introduces ontologies, drawing from the current literature on knowledge representation and reasoning.

In Section 4.2 we concentrate on the practical applications of ontologies.

Next we focus on the e-LIS ontology itself: Section 4.3 describes its domain and aims; Section 4.4 explains the e-LIS ontology, its developing strategy and its roles within the e-LIS project; Section 4.5 discusses possible ways to empower the e-LIS ontology with rules for specific classes of LIS signs.

Section 4.6 describes the software we used in developing the ontology. Finally, Section 4.7 presents a first test of the query tool of SEWASIE with our e-LIS ontology.

4.1 What is an ontology?

The word ontology comes from the Greek *ontos* for being and *logos* for word. It is a relatively new term in the long history of philosophy, introduced by the 19th century German philosophers to distinguish the study of being as such from the study of various kinds of beings in the natural science [17].

According to a more formal and modern characterization [17], an ontology is a "catalog of the types of things that are assumed to exist in a domain of interest D". Classes and associations are the core ingredients of most ontologies. Thus an ontology for D is given by

- *classes*, namely, subsets of D;

- *associations*, namely, relations of arity $n \geq 2$ over D (that is, subsets of D^n with $n \geq 2$).

Moreover an ontology can also specify cardinality constraints on associations, subset relations between classes/associations, as well as disjointness and covering constraints. We do not enter in details on these, and refer the reader to [16] for their formal characterization.

Instead we provide some examples of the above definitions. In our e-LIS ontology, the *One-hand sign* class is a subset of the *Simple Sign* class, as the latter specifies a more general concept than the former. By inspection of [15], we also learned that each one-hand sign has precisely one handshape as parameter. To express this, in our ontology we have the following: an association between the terms of the *One-hand sign* class and those of the *Handshape* class; a cardinality constraint *equal to one* is then added in the ontology to express that there is exactly one *Handshape* term for each *One-hand sign* term. See also Figure 4.1 for the related snippet of the e-LIS ontology in diagrammatic form.

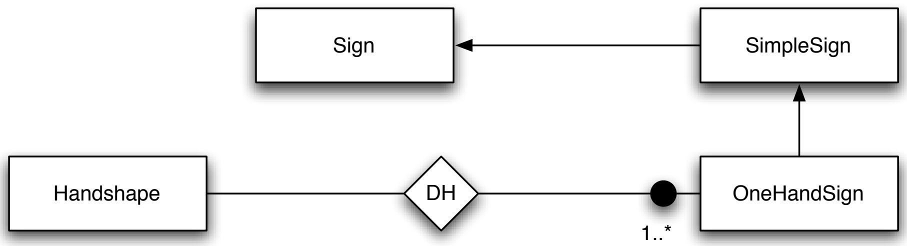

Figure 4.1: Snippet of the e-LIS ontology diagram.

According to [8], ontologies can be further distinguished according to their level of generality:

- *top-level ontologies* describe very general concepts, which are independent of the specific problem or domain;
- *domain ontologies* and *task ontologies* describe, respectively, the vocabulary related to a generic domain or a generic task or activity, by specializing the terms introduced in the top-level ontology;
- *application ontologies* describe concepts depending both on a specific domain and task, which are often specializations of both the related ontologies.

In what follows, we concentrate on the many uses of ontologies and then we zoom in on the e-LIS ontology, characterizing it as a domain ontology.

4.2 The many uses of ontologies

4.2.1 The ontology for the domain analysis

Common vocabulary for researchers. An ontology defines a common vocabulary for researchers who need to structure and share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them [13].

Sharing common understanding of the structure of information. Sharing common understanding of the structure of information among people or software agents is one of the more common goals in developing ontologies [12].

Enabling reuse of domain knowledge. Enabling reuse of domain knowledge was one of the driving forces behind recent surge in ontology research. If one group of researchers develops some ontology in detail, others can simply reuse it for their domains. Additionally, to build a large ontology, we can integrate several existing ontologies describing portions of the large domain. We can also reuse a general ontology and extend it to describe our domain of interest [13].

Making explicit domain assumptions. Making explicit domain assumptions underlying an implementation makes it possible to change these assumptions easily if our knowledge about the domain changes. Hard-coding assumptions about the world in programming-language code makes these assumptions not only hard to find and understand but also hard to change, in particular for someone without programming expertise. In addition, explicit specifications of domain knowledge are useful for new users who must learn what terms in the domain mean [17].

Separating the domain knowledge from the operational knowledge. Separating the domain knowledge from the operational knowledge is another common use of ontologies. We can describe a task of configuring a product from its components according to a required specification and implement a program that does this configuration independent of the products and components themselves [11].

Analyzing domain knowledge. Analyzing domain knowledge is possible once a declarative specification of the terms is available. Formal analysis of terms is extremely valuable when both attempting to reuse existing ontologies and extending them [10].

4.2.2 The ontology for the database and the search engine

Database conceptual modeling. The most obvious use of an ontology is in connection with the database component. In fact, the ontology can be compared with the schema component of the database. At the development time, an ontology can play an important role in the requirement analysis and conceptual modeling phase. The resulting conceptual model can be represented as a computer processable ontology [8].

Navigation and query system. Another very important use of an ontology is dynamic management of queries in connection with the user interface component. Since ontologies embody semantic information on the constraints imposed on the classes and relationships used to model given domain and task, they can be used to generate a form-based interface that check for constraint violations. At the run time, the first role an ontology can play within the user interface is to offer the user a query and navigation system.

Information integration. Another example of use of ontologies at development time is information integration: a common conceptual schema to be used for instance in a data warehousing application can be built by mapping heterogeneous conceptual schemes on a common top-level ontology [8].

4.3 The e-LIS ontology: domain and aims

4.3.1 Domain of the e-LIS ontology

The domain of the ontology is composed of signs of LIS (see Section 2.1 above), and is based on the the transcription system of [15]. This is the system chosen by the e-LIS team for the electronic dictionary (see also Section 2.3 above). Albeit it only transcribes manual signs, the ontology created in e-LIS could be easily extended with non manual signs. We discuss this issue in Chapter 5 below.

Following the terminology of Section 4.1, ours is an *domain ontology.*

4.3.2 Aims of the e-LIS ontology

Looking up for a sign in a LIS dictionary such as [15] is not an easy task. As discussed in Section 2.3, the reading order of [15] is not intuitive and requires some knowledge of LIS. In our view, users of the e-LIS dictionary are not only people literate of LIS but every interested person with any knowledge of LIS, of any age or from any group, for example children. Therefore we aim at building an ontology which requires no literacy of LIS to guide the unexperienced user during her/his search in the electronic dictionary.

The design of the navigation interface should then be based on the e-LIS ontology. The interface will also offer users a query system to retrieve the data stored in the e-LIS database. Therefore the general-level motivations to the use of an ontology described in Section 4.2 are all applicable to the case of our e-LIS ontology.

A knowledge base developed on the e-LIS ontology should then be able to answer questions related to characteristics of signs or classes of signs, such as the following ones.

- Which kinds of movements are consistent with the Two-Hand Sign?
- Which categories does the One Hand Sign take?
- Of which components is built the Palm Orientation?
- Is the given combination of components consistent?

4.4 The e-LIS ontology: its definition

Our e-LIS ontology is based on the Stokoe-based transcription system of [15]. Our ontology needs to take into account its categories (explained in Section 2.3) as well as their implicit relations — which requires a deep analysis of the dictionary.

In other words, our ontology refines and gives 'more structure' to the transcription system of [15], without changing the basic rules for the production of signs. By introducing new classes and adding relations in the ontology, we can make explicit relevant pieces of information which are implicit and somehow hidden in [15]. For instance, by creating a relation which expresses a dependency between the *OneHandSign* class and the *Handshape* class; or by grouping together related concepts in new more general concepts, such as the *Movement in circle* class which, in our ontology, is the 'container' all of the 12 different types of cyclic movements listed in [15].

As claimed in [14], Stokoe-based notations can be successfully employed primarily for notating single de-contextualized signs, as in most SL dictionaries. However:

> there are no monolingual dictionaries or reference grammars that rely on this notation as the primary and unique means for representing the SL signs they describe. The "representation-by-notation" given in such reference tools is not autonomous, but it is always substantially integrated with text descriptions in a specific written language (e.g.,

One-hand sign:
$\mathbf{H}_{[DH]}\ \mathbf{O}^*_{[DH]}\ \mathbf{C}^*_{[DH]}\ \mathbf{Loc}_{[DH]}\ ^{MovMov^*Mov^*}$

Two-hand sign:
$\mathbf{H}_{[NDH]}\ \mathbf{O}^*_{[NDH]}\ \mathbf{R}^*_{[DH-NDH]}\ \mathbf{H}_{[DH]}\ \mathbf{O}^*_{[DH]}\ \mathbf{C}^*_{[DH]}\ \mathbf{Loc}_{[DH]}\ ^{MovMov^*Mov^*}$

Table 4.1: One-hand sign and Two-hand sign.

> English, Italian, Spanish), and graphic, pictured or filmed illustrations of the signs described. These descriptions are in no way comparable to those we find in dictionaries and reference grammars for spoken languages.

On the light of this, Pizzuto et al. pose the following questions:

> Isn't it the case [...] that the difficulties we find in using Stokoe-based notations for transcribing signed texts reveal a need to revise our current analysis of SL structure much more profoundly and extensively than it is commonly assumed?

Our ontology wants to be a first step in this direction.

In the remainder of this section, we focus on the classes and associations of the ontology, explaining their role and our motivations for their creation.

In the following, we restrict our exposition to the essential features of the ontology. For instance, cardinality constraints are missing in our below exposition, because these can be easily understood from our ontology diagram in [5]. However, note that they are integral part of our e-LIS ontology.

4.4.1 One-hand sign and Two-hand sign

Given the following symbols

- **H** for handshape,
- **O** for palm orientation,
- **C** for contact with location,
- **Loc** for location,
- **Mov** for movement,
- **R** for a relation between hands
- **DH** for dominant hand,
- **NDH** for non-dominant hand,

we can abstract from [15] the definitions of one-hand sign and two-hand sign as in Table 4.1. The asterisk (*) means that a symbol may not occur.

4.4.2 Composed versus simple signs

A composed sign is one of the four sequences in Table 4.2. Then in our ontology the abstract class "*Sign*" becomes the top class of the ontology; next we have its subclasses *Composed sign* and *Simple sign*. *One-hand sign* and *Two-hand sign* are subclasses of *Simple sign*.

According to the definition of one-hand sign and two-hand sign given in Table 4.1, they must be composed of movement (**M**), location (**Loc**) and contact with location (**C**).

However they differ in the amount of information regarding the handshape (**H**), the palm orientation (**O**) and the relational position of hands (**R**); thus our e-LIS ontology has specific assertions expressing this and involving the related subclasses, *One-hand sign* and *Two-hand sign*, as explained below.

One-hand sign	One-hand sign
One-hand sign	Two-hand sign
Two-hand sign	One-hand sign
Two-hand sign	Two-hand sign

Table 4.2: Composed sign.

Location and contact with location

The properties

- contact with location,
- location,
- and movement

are common to the *One-hand sign* and *Two-hand sign* classes. In the ontology those properties become associations between the *Simple sign* class and the *Contact with location*, *Location* and *Movement in sequence* classes.

According to our analysis of [15], the location is specified for the dominant hand only. The same concerns "contact with location", which is specified in [15] for the dominant hand only.

In general, whether some categories are related to the dominant or the non dominant hand is expressed in the e-LIS ontology through the name of an association.

The *Location* class has been further subdivided by us into four main subclasses:

- *Neutral space in front of the body*;
- *Arm or its part* (with subclasses: *Wrist*, *Arm*, *Not dominant hand*);
- *Trunk* (with subclasses: *Lower trunk and hip*, *Chest*, *Shoulders and upper trunk*);
- *Neck and above* (with subclasses: *Neck*, *Whole face*, *Part of face*).

Finally, the *Part of face* subclass is divided into:

- *Cheek*;
- *Chin*;
- *Eye*;
- *Top and sides of the head*;
- *Mouth*;
- *Nose*;
- *Ear*.

All the above classes, with the exception of the following abstract concepts

- *Arm or its part*,
- *Trunk*,
- *Neck and above*,
- *Part of face*,

are also listed as locations in [15].

By inspection of [15], we can see that there are two possible kinds of contacts with body: the first one is the hand contact and the other one is the finger contact. So in our ontology we have the *Contact with location* class with two subclasses, namely,

- *Contact with hand*,
- *Contact only with fingers*.

Next there is an association between the *Contact with location* class and the related *Location* class to express the contact of either the hands or the fingers with a body part.

Moreover we have also an association between the *Contact with location* class and the *Hand or hands initial position* class to show that, according to [15], *contact with location* is part of the *Hand or hands initial position*. The others are *palm orientation* and *hands relational position*, which are described below.

Movement

The movement category of [15] is the most complex one. The whole movement has one or more sequences, which are built of one single hand/hands' movement. To account for this behavior, our ontology has the *Movement in sequence* class and the *Movement* class, as well as an association between them to express that the *Movement in sequence* class is responsible for building sequences of movements.

The movement itself is built of two kinds of components:

- one-hand movement component;
- relational movement component.

Then in the ontology we have the *One-hand movement component* class with subclasses:

- *Movement in circle* (with subclasses: *Convex clockwise frontal*, *Convex clockwise horizontal*, *Convex clockwise vertical*, *Convex anticlockwise frontal*, *convex anticlockwise horizontal*, *convex anticlockwise vertical*, *Concave clockwise frontal*, *Concave clockwise horizontal*, *Concave clockwise vertical*, *Concave anticlockwise frontal*, *Concave anticlockwise horizontal*, *Concave anticlockwise vertical*);
- *Directed movement* (with subclasses: *Right*, *Left*, From side to side, *Towards the signer*, *Towards and away from the signer*, *Away from the signer*, *Down*, *Up*, *Up and down*);
- *Finger movement* (with subclasses: *Crumbling*, *Finger bending at the palm knuckles*, *Finger bending at knuckles*, *Wavelike movement and fingers drumming*);
- *No movement*;
- *Touch* (with subclasses: *With hand*, *With fingers only*);
- *Wrist movement* (with subclasses: *Twisting at the wrist*, *Bending at the wrist*. The class *Bending at the wrist* can be further subdivided into the classes: *Wrist bending forwards*, *Wrist bending sideways*, *Wrist bending backwards*);
- *Closing hand or fingers*;
- *Opening hand or fingers*;
- *Configuration change*.

The *Relational movement component* class stands for the components of movement, which expresses movement of one hand with respect to the other. These are:

- *Hand insertion*;
- *Crossing hands*;
- *Hands away from each other*;
- *Hands towards each other*;
- *Change place of hands*;
- *Hands interlinking.*

Finally our ontology has the *Movement Attribute* class; the related category exists also in [15]. The class has the following subclasses:

- *Elbow stretching*;
- *Slow movement*;
- *Held movement*;
- *Stretched movement*;
- *Continuous movement*;
- *Finger sequential movement*;
- *One time repeated*;
- *Alternating movement.*

The *Relational movement component* class has an association with the *Two-hand sign* class, to express that the relational movement is part of the two-hand sign. To make it clear that this association concerns both hands, we made the association inherit from the associations:

- between *Simple sign* class and the *Movement in Sequence* class, for dominant hand;
- between *Two-hand sign* class and *Movement in Sequence* class, for non dominant hand.

For the *Touch* class we have an association with the *Location* class, because in LIS the movement of type "touch" is related to the signer's body. The only exception is the *Neutral space in front of the body* as location. In this case the sign is a two-hand sign and the movement of type "touch" concerns the contact of both hands (see sign 700.1 in [15]).

Handshape

Now we focus on the handshape category, which is specified for the dominant hand only in one-hand signs (1). In two-hand signs it is specified for the dominant hand (2) and the non dominant hand (3). Following this logic our ontology has *Handshape* as a class and three associations for 1, 2 and 3.

The *Handshape* class has as directed subclasses all eleven subgroups of handshapes listed in [15]:

- *Extensions* (with subclasses: *Ext-V*, *Ext-Y'*, *Ext-I*, *Ext-S*, *Ext-Y*, *Ext-L*, *Ext-3/5*, *Ext-3*, *Ext-4*, *Ext-5*);
- *Opening* (with subclasses: *Op-L*, *Op-F*, *Op-G*, *Op-T*, *Op-I*, *Op-5*, *Op-4*, *Op-3*, *Op-3/5*);
- *Closing* (with subclasses: *Cl-F*, *Cl-Bv*, *Cl-L*, *Cl-As*, *Cl-3*, *Cl-5*);
- *Closed* (with subclasses: *CLs-3*, *CLs-5*, *CLs-L*, *CLs-F*);
- *Crumblinglike* (with subclasses: *Cr-F*, *Cr-L*, *Cr-5*);
- *Round shaped* (with subclasses: *Ro-O*, *Ro-F*, *Ro-3/5*);
- *Closed fists* (with subclasses: *Fi-T*, *Fi-As*, *Fi-A*);
- *Rectangular* (with subclasses: *Re-H*, *Re-L*, *Re-F*, *Re-B*);
- *Curved* (with subclasses: *Cu-B*, *Cu-F*, *Cu-G*, *Cu-5*, *Cu-3*, *Cu-V*, *Cu-C*, *Cu-C'*);
- *Flat shaped* (with subclasses: *Fl-B*, *Fl-G*, *Fl-H*, *Fl-G'*);
- *Others* (with subclasses: *Ot-D*, *Ot-R*).

During the development of the graphical user interface, special attention should be payed to the change of handshape. The handshape of type *opening* and *closing* are dynamic; *the handshape always changes from a particular handshape to another particular one*, but this information is not included in the ontology. However it can be written in external definitions. The handshape changes also due to the following kinds of movement:

- *Closing hand or fingers*;
- *Opening hand or fingers*;
- *Configuration change* (the handshape changes to *some* other handshape).

To express this we created three associations between the *Handshape* and the *Closing hand or fingers*, *Opening hand or fingers*, *Configuration change* classes. Moreover we created five associations for all the fingers of the hand between the *Handshape* and *Finger state* classes. The *Finger state* class does not exist in [15]. We have it explicitly in our ontology to show that the configuration depends on a given state of the fingers:

1. *Finger closed*;
2. *Finger straight*;
3. *Finger bent*;
4. *Finger bent at palm knuckles*.

The movement of type *handshape change* is not listed in tables in [15], however it occurs in the sign transcription (see 361.3 in [15]). Another new class, not present in [15], is the *Finger contact* class. It has the following subclasses:

- *Thumb with middle finger*;
- *Thumb with little finger*;
- *Thumb with index finger*;
- *Thumb with ring finger*;
- *Index finger with middle finger*.

Palm orientation

As in the case of the handshape category, the palm orientation category is specified for the dominant hand in the one-hand sign (1), for the non dominant hand (2) and the dominant hand (3) in the two-hand sign. Then the ontology has the *Palm orientation* class and three associations for 1, 2, and 3 above.

According to [15], the *palm orientation* is part of the *hand or hands initial position* class. To express this idea we have an association between the *Palm orientation* class and the *Hand or hands initial position* class.

As next step we have an association between the *Palm orientation* class and the *Palm orientation component* class. Following [15], this has the following subclasses:

- *Palm towards the signer*;

- *Palm down*;
- *Palm up*;
- *Palm away from the signer*;
- *Palm left*;
- *Palm right*.

Hands relational position

The last part of the *Hand or hands initial position* class is the *Hands relational position* class; thus we have an association to express this.

As next we have the association between the *Hands relational position* class and the *Hands relational position component* class, which are subdivided into three classes:

- *Right-left contact* (with subclasses: *Hands contacted*, *Fingers contacted only*, *Contact with elbow*);
- *Right-left distance* (with subclasses: *Small distance*, *Big distance*);
- *Right-left spatial position* (with subclasses: *Hands crossed*, *Hands interlinked*, *One hand inside the other*, *Left in front of right*, *Right in front of left*, *Right higher than left*, *Left higher than right*).

4.5 Concluding remarks on the e-LIS ontology

Regarding the location and movement categories of [15], some additional observations are in order. Strictly speaking, these are *not* included in the ontology. However it is possible to *add them to the ontology as additional axioms* — e.g., in the form of description logic formulae. We elaborate on them as follows.

4.5.1 Additional observations regarding location

In general, in the simple two-hand sign, the dominant hand and the non dominant hand have the same location.

An exception to the above rule is given by signs with *non dominant hand*, *arm* or *wrist* as location categories, where the non dominant hand becomes a location itself — see sign 108.1 in [15].

Another exception is the composed sign, where the location for the non dominant hand and the location for the dominant hand can be different (see 197.3 and 184.2 in [15]).

4.5.2 Additional observations regarding movement

According to our own observations, the movement category in the notation system by [15] is only concerned with the dominant hand or both hands (the dominant hand moves and the non dominant hand does not move at all). Sometimes some componets of the movement concern the dominant hand while the other components concern the non-dominant hand (see sign 184.2 in [15]); 'which is which' is not explicitly annotated in [15].

In case the movement is composed of relational movement components, such as *hands away from each other* or the *alternating movement* attribute, the behavior of two hands is specified in a clear way and it is not difficult to understand it.

By careful inspection of [15], one can see that most of the two-hand signs with identical handshape and palm orientation have symmetric or alternating movements (e.g., see 741.1 or 140.3 in [15]). However this is not a general rule (e.g., see 630.2 in [15]). The two-hand signs with the same handshape and movement are called "symmetric".

In order to be able to distinguish if the sign is symmetric (thus to be sure that both hands move), attention should be payed to the location category. The locations

- *non-dominant hand*
- *arm*
- *wrist*

imply that only the dominant hand moves, even if the relational hand movement component is present, as in the case of interlinking hands (see 739.1 in [15]). The two-hand signs with such location are called "asymmetric" [15]. Thus knowing the location we can deduce the movement of each hand. The problem is that we cannot rely on the information regarding the location that the user provides us with. To define the location correctly, the user should know the rules for movement, which we cannot expect she/he to know precisely (see 655.2 or 145.1in [15]). That is why we choose to ask the user explicitly about the movement of the non dominant hand, and to include this information in the ontology.

Another observation of interest for the design of the user interface, but not included in the ontology, is the fact that, in the asymmetric signs, the *open hand* and *closed fist* handshapes for the non dominant hand are very frequent [21].

These handshapes are called FL-B and Fi-A respectively in the e-LIS ontology (see Appendix A).

4.6 Ontology editor tools

We created the diagram of the e-LIS ontology using the ICOM Ontology Design tool [6].

About ICOM

ICOM is an advanced CASE tool which allows the user to design multiple extended Entity-Relationship diagrams, developed at FUB [6].

Complete logical reasoning is employed by the tool to verify the specification, infer implicit facts, devise stricter constraints, and manifest any inconsistency. The intention behind ICOM is to provide a simple, freeware conceptual modeling tool that demonstrates the use of, and stimulates interest in the novel and powerful knowledge representation based technologies for database and ontology design.

The conceptual modeling language supported by ICOM can express:

- the standard Entity-Relationship data model, enriched with IsA links (i.e., inclusion dependencies), disjoint and covering constraints, full cardinality constraints, and definitions attached to entities and relations;
- aggregated entities together with their multiple hierarchically organized dimensions — e.g., it is possible to represent multidimensional cubes over star and snowflake schemes;
- rich class of (interschema) integrity constraints, as inclusion and equivalence dependencies between view expressions involving entities and relationships possibly belonging to different schemes.

We decided to use ICOM for several reasons. First of all, it allows us to define the ontology as an Entity-Relationship diagram. An ontology in diagrammatic format makes it easier to keep track of its contents and "global" structure rather than a textual format such as DIG[1]. This is particularly true of a complex ontology such as the e-LIS ontology; it has more than 140 classes, and there is a disjoint constraint for almost all pairs of classes. Having the ontology in diagrammatic form also simplifies discussions with other team members who are not ontology

[1] The DIG interface (often just known as DIG) provides uniform access to Description Logic Reasoners. The interface defines a simple protocol (based on HTTP PUT/GET) along with an XML Schema that describes a concept language and accompanying operations.

experts. Finally, with ICOM it was possible to check and ascertain that our e-LIS ontology is consistent.

About Protégé

Protégé is a free, open-source platform that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies. At its core, Protege implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats. Protégé can be customized to provide domain-friendly support for creating knowledge models and entering data. Further, Protégé can be extended by way of a plug-in architecture and a Java-based Application Programming Interface (API) for building knowledge-based tools and applications [19].

The Protégé platform supports two main ways of modeling ontologies:

- the Protégé-Frames editor enables users to build and populate ontologies that are frame-based, in accordance with the Open Knowledge Base Connectivity protocol (OKBC). In this model, an ontology consists of a set of classes organized in a hierarchy to represent a domain's salient concepts, a set of slots associated to classes to describe their properties and relationships, and a set of instances of those classes;
- the Protégé-OWL editor enables users to build ontologies for the Semantic Web, in particular in the W3C's Web Ontology Language (OWL). An OWL ontology may include descriptions of classes, properties and their instances. Given such an ontology, the OWL formal semantics specifies how to derive its logical consequences, i.e., facts not literally present in the ontology, but entailed by the semantics. These entailments may be based on a single document or multiple distributed documents that have been combined using defined OWL mechanisms.

We decided to use Protégé in addition to ICOM. In fact, Protégé produces ontologies in a DIG format which is compatible with the SEWASIE Query Tool, whose role is described in Subsection 4.7 below.

4.7 E-LIS and SEWASIE

SEWASIE

SEWASIE (SEmantic Webs and AgentS in Integrated Economies) is an intelligent tool to support the business of small and medium-sized enterprises in the

Internet [16]. In particular, the SEWASIE Query component allows the user to pose queries to the Sewasie system, exploiting the full capacities of the underlying ontology based architecture. The Query Building Module assists the user in composing her/his query.

The Sewasie Query Tool and the e-LIS ontology

The aim of our test is to check if the query system of SEWASIE is suited to the needs of e-LIS. Here we focus on the query building mechanism itself. The graphical user interface of the SEWASIE Query Tool is beyond the interest of our current work and test.

The program allows us to load the ontology in XML, DIG and ODL format. Our test is performed with the part of the e-LIS ontology written with Protégé and saved in DIG format.

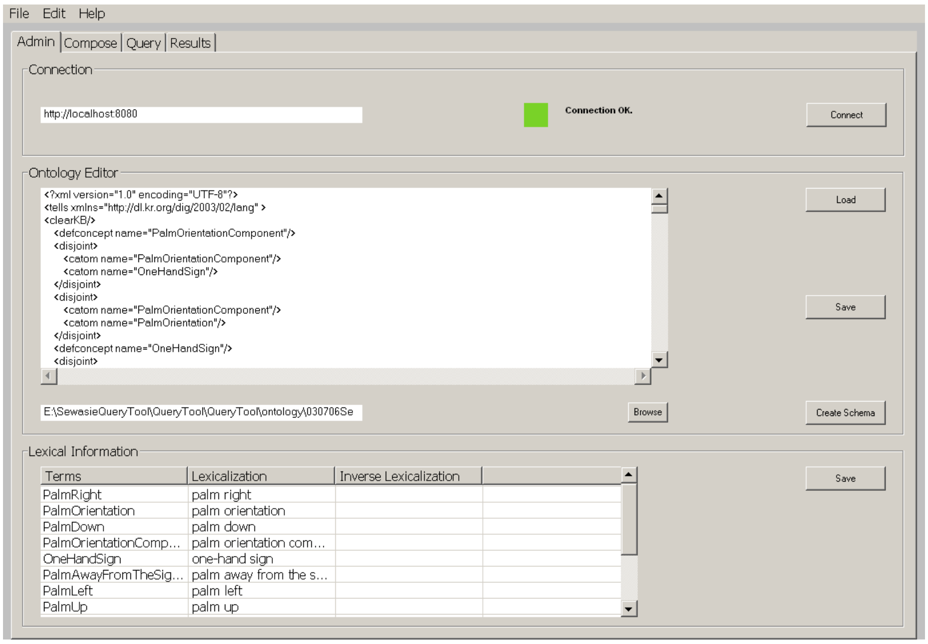

Figure 4.2: SEWASIE Query Tool, register Admin

The program interface consists in 4 registers:

- *Admin*;
- *Compose*;
- *Query*;
- *Results*.

Using the buttons of the first register we can load the ontology and create the schema. The terms from the ontology are listed at the bottom of the register in the first column of the "lexical information" table. The second and third columns, *lexicalization* and *inverse lexicalisation*, allow user to edit the lexical terms for each class and property on the ontology, listed in the first column of the table, as shown in Figures 4.2 above.

In the *Compose* register the query is represented graphically as a tree. After right clicking on the top of the tree, users are asked to choose the starting term from the shown list of the lexical terms built in the previous register. The possible operations on the query are accomplished using the pop-up menu associated to each node in the tree; see Figure 4.3 below. These are:

1. *Add compatible*; once clicked, it lists the classes not declared as disjoint with the selected class;

2. *Add property*, once clicked, it lists all the properties (e.g., associations and attributes) available for the selected class;

3. *Substitute*, once clicked, it lists the subclasses, superclasses and the equivalent classes of the selected class.

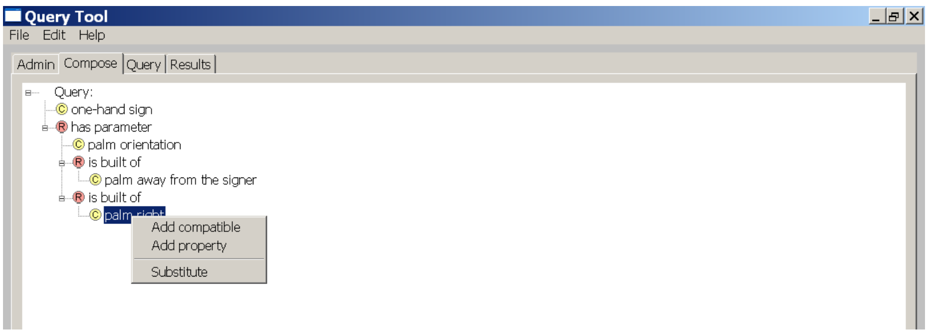

Figure 4.3: SEWASIE Query Tool, pop-up menu

The *Query* register shows the XML and SQL query created automatically for the tree in the *Compose* register. Unfortunately we could not test the *Query* register, because the database of e-LIS did not exist at the moment of writing this thesis. It will be indeed very important to repeat the test with the populated database.

According to our preliminary observations, the tree building mechanism of the Query Tool on the e-LIS ontology works correctly. Following our e-LIS ontology, the system suggests only operations which make sense for the currently selected term. The user can then specify her/his request in an iterative manner.

Although the database component is still mising, the integration of e-LIS with the Query Tool of SEWASIE looks promising. However several issues still need to be addressed. We speculate on them in Chapter 5 below.

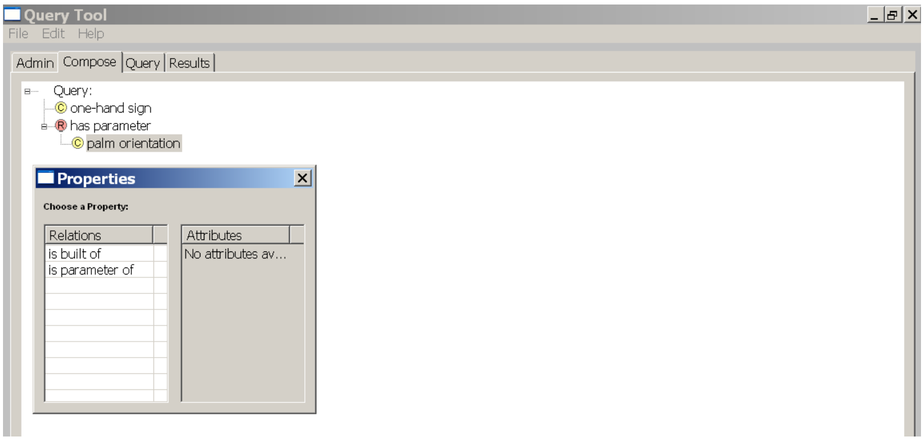

Figure 4.4: SEWASIE Query Tool, properties

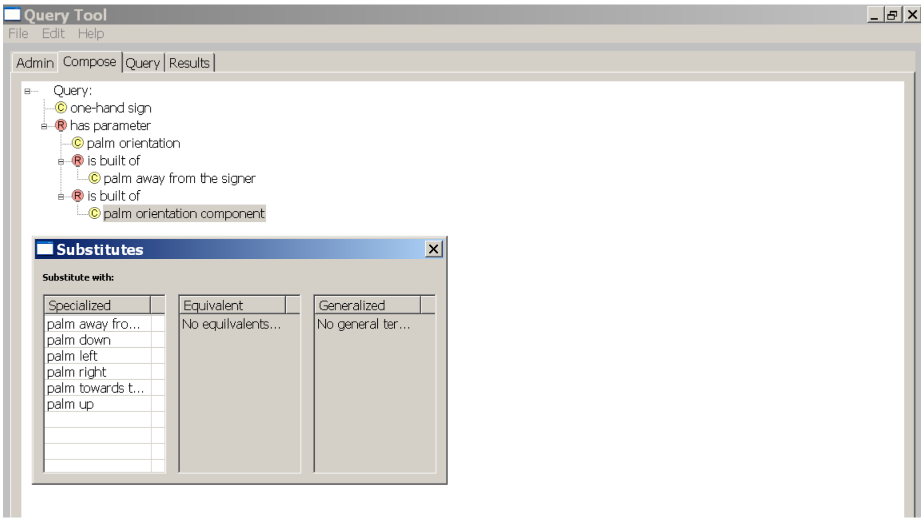

Figure 4.5: SEWASIE Query Tool, substitutes

Chapter 5

Conclusions and Future Work

This chapter provides the conclusion to our thesis work. We compare our ontology-based dictionary with similar projects for SL's in Section 5.1. Then Subsection 5.2.1 lists some of the benefits and drawbacks of our ontology-based approach to e-LIS. We conclude with some considerations for future work in Subsection 5.2.2.

5.1 Related work

Electronic dictionaries for SL's offer numerous advantages over conventional paper dictionaries. For instance, due to the inherent difficulty of the Stokoe-based notation, the ordering of signs in [15] is rather unclear to LIS non-experts (see Section 2.3). Therefore the search for a sign requires a good knowledge of LIS, making the consultation of [15] not easy for users unexperienced of LIS. The e-dictionary, based on the intensive navigation and intelligent search engine offered by the ontology, should simplify and speed up the search process. More in general, SL e-dictionaries bring several advantages over paper dictionaries for they can make use of the multimedia technology to represent dynamic contents, such as the movement of the hands.

Such advantages became obvious to the developers of a bidirectional Multi-Media Dictionary for American SL (MM-DASL) [22]. Alas, the project was never released for commercial use for a number of reasons carefully examined in [22].

MM-DASL developed a special user interface, with film-strips or pull-down menus. This allows users to look up for a sign only reasoning in terms of its formational features, namely, the Stokoe categories (handshape, location and movement); search is constrained via linguistic information restricting their possible combinations. The MM-DASL interface is not dynamic, whereas that of e-LIS is conceived as a dynamic interface.

In the MM-DASL project, the user is not required to specify all the sign's formational components, nevertheless there is a specific order in which she/he should construct the query. Instead the ontology-driven search engine allows the user to construct the query in a more flexible way. Since the ontology embodies semantic information on the constraints imposed on the classes and relations used to model the LIS dictionary domain, it can be used to generate a form-based interface that eliminates constraint violations. The query building procedure in e-LIS is then a sequence of steps, where the current ones depend on the previously chosen steps. However, as highlighted in [22], the search engine should be able to retrieve not just signs, which exactly match the search criteria, but also the signs that come very close to matching these criteria; this is also our concern, discussed in Section 5.2.2 below.

Platform independence of the system was a problem for MM-DASL; this is an issue the e-LIS team is taking into account, thus the choice of having the e-LIS dictionary as a web application. Last but not least, the profile of the target user was not analyzed before starting MM-DASL, whereas, as explained in Chapter 3, we aim at a dictionary non-experts of LIS can use.

A bidirectional dictionary for Flemish SL, still under development, is [1]. Users are presented with images for the parts of the body involved in the sign formation; by clicking on each body part, the user has at disposal the notation symbols she/he can choose for that body part. Users are not guided through the selection process, so that non-experts of Flemish SL and the chosen notation system are likely to choose combinations leading to meaningless gestures, that is, not corresponding to any Flemish SL sign.

Similar remarks apply to other on-going projects of electronic dictionaries. For instance, the bidirectional e-dictionary for German SL developed at Hamburg is [3]; users are asked to choose from four categories of images, each representing a sign formational component. There are only 22 pictures to simplify the design of the interface, e.g., by grouping more than one handshape in one image.

Another bidirectional dictionary for German SL is [4]. This also requires the user to know well the chosen sign notation system; users search for a sign by entering directly strings in HamNoSys, a rather rich and complex notation system we described in Chapter 2.

In general, e-dictionaries for SL's are monodirectional, i.e., from the national VL to the corresponding SL. Moreover, as remarked in [14], the notation in the chosen transcription system is always integrated with text descriptions in the related VL. On the contrary, the e-LIS dictionary aims at describing and contextualising signs also using LIS as meta-language.

5.2 Looking backwards and ahead

5.2.1 Benefits of our ontology-based approach

As highlighted in the technical reports of [16], ontologies define "a vocabulary which is richer than the logical schema of the underlying data, and it is meant to be closer to the user's rich vocabulary". This is particularly true of the e-LIS ontology. Users of the e-LIS dictionary will be able to take full advantage of the enriched knowledge provided by the underlying ontology. The ontology will expertly guide them in their search for a sign and thus provide an *intensional navigation*; again quoting [16], the intensional navigation can help a less skilled user during the initial step of sign search.

The improved and automated query capability on the underlying database is the other main advantage of our e-LIS ontology. Alas, we could not test this because the e-LIS database was not populated at the time of writing this thesis.

Summing up, our ontology-based approach brings the following benefits to the e-LIS project:

- even non-expert users should be able to search for signs thanks to the intensional navigation made possible by the e-LIS ontology;
- our ontology enriches the e-LIS dictionary with expert information concerning (classes of) LIS terms and their mutual relations; then the SEWASIE query tool permits to exploit it for the automated extraction of signs from the database;
- due to the automated reasoning engines available with Protégé and ICOM, as well as with other ontology editors, we can check if our e-LIS ontology is consistent.

In particular, a knowledge base developed on the e-LIS ontology should then be able to answer questions related to characteristics of signs or classes of signs, such as: which kinds of movements are consistent with the Two-Hand Sign? Is the given combination of sign components consistent?

5.2.2 Future work

The current format of the query interface requires the knowledge, albeit very limited, of Italian Verbal Language (VL). For born-deaf people reading is as serious a problem as speaking the VL because it involves knowing and thinking in terms of sounds. This is a problem that must be addressed during the development of the graphical user interface. The ontology terms should be associated with self-explanatory graphic symbols.

However, it is not straightforward how to visualize classes such as “finger state”. This poses serious and not-easy challenges to the designers of the graphical interface. The class “movement” and its subclasses are the hardest of all. On top of this, to our knowledge there are no 2D or 3D editors that non-experts can use ‘as is’ to animate signs.

Another big challenge is the creation of a concept which allows us to distinguish between single sign, composed sign and two different signs.

Axioms for specific rules of LIS can be studied and added to the e-LIS ontology. For example, we can add to it the following information concerning asymmetric signs: the *wrist* or *arm* locations for the dominant hand imply no movement for a non-dominant hand (compare Section 4.5).

Moreover, albeit it only transcribes manual signs, the ontology created in e-LIS could be easily extended with non manual signs. This would require a deep knowledge of LIS and possibly a richer transcription system than the one of [15].

However some care is in order here: the expressive power of the transcription system, or of the ontology itself should not come to the price of its simplicity of use; our aim is that the ontology can also guide non experts of LIS. Now, the inherent ambiguity of LIS and of the Stokoe-based transcription system we adopted may already let unexperienced users make erroneous choices. In order to tackle this kind of problems,

- we can refine our current ontology, for instance, by adding relations between ‘ambiguously similar classes’,
- we can develop a ‘fuzzy’ query search method,
- or we can adopt a mixture of the above two solutions.

As for the integration of e-LIS with SEWASIE, several questions remain open for future investigation; we list them as follows.

- How should we deal with decision loops which allow the user to back up to the ‘previous class’, which mapped into a query can result in bad performance results?
- How to combine the query building mechanism of the SEWASIE Query Tool with the graphical user interface of the e-LIS dictionary?
- How much effort should be spent in adjusting SEWASIE to the needs the of the e-LIS web application (or vice versa), knowing that the SEWASIE

query tool was written in JAVA while the Internet pages for e-LIS (that is, the user's forum) is in VB.NET?

The usability evaluation and more systematic feasibility tests of our ontology-based approach should be carried on as soon as possible.

Appendix A

LIS symbols

Sign

Composed sign

Simple sign

One-hand sign

Two-hand sign

Movement

Movement in sequence

One-hand movement component

Movement in circle:

	Convex clockwise frontal
	Convex anticlockwise frontal
	Concave clockwise frontal
	Concave anticlockwise frontal
	Convex clockwise horizontal
	Convex anticlockwise horizontal
	Concave clockwise horizontal
	Concave anticlockwise horizontal
	Convex clockwise vertical
	Convex anticlockwise vertical

[illegible]	Concave clockwise vertical
[illegible]	Concave anticlockwise vertical

Directed movement:

∧	Up
∨	Down
N	Up and down
>	Right
<	Left
Z	From side to side
T	Towards the signer
⊥	Away from the signer
I	Towards and away from the signer

Finger movement:

ɱ	Crumbling
[illegible]	Finger bending at knuckles
ɼ	Finger bending at the palm knuckles
[illegible]	Wavelike movement and fingers drumming
Ø	No movement

Wrist movement:

ω	Twisting at the wrist

Bending at the wrist:

ͻ	Wrist bending forwards
ɕ	Wrist bending backwards
ᴗ	Wrist bending sideways

Touch:

×	With hand
*	With fingers only

◘	Opening hand or fingers
◘	Closing hand or fingers

Handshape change

Closing hand or fingers

Opening hand or fingers

Movement Attribute:

✓	Elbow stretching
ʕ	Slow movement
ǀ	Held movement
!	Stretched movement
~	Alternating movement
••	Continuous movement
⸝	Finger sequential movement
•	One time repeated

Relational movement component:

)(	Hands towards each other
÷	Hands away from each other
+	Crossing hands
⌛	Hands interlinking
⊙	Hand insertion
‹›	Change place of hands

Location:

Ø	Neutral space in front of the body

Arm or its part:

Ʊ	Wrist
\	Arm
N	Not dominant hand

Trunk:

ʮ	Lower trunk and hip
[]	Chest
⌜⌝	Shoulders and upper trunk

Neck and above:

Π	Neck
○	Whole face

Part of face:

ʒ	Cheek
∪	Chin
⊔	Eye
∩	Top and sides of the head
ᴗ	Mouth
Δ	Nose
ɔ	Ear

Hand or hands initial position

Contact with location:

×	Contact with hand
*	Contact only with fingers

Palm orientation

Palm orientation component:

∧	Palm up
∨	Palm down
>	Palm right
<	Palm left
⊤	Palm towards the signer
⊥	Palm away from the signer

Hands relational position

Hands relational position component

Right left contact:

×	Hands contacted
*	Fingers contacted only

gd — Contact with elbow

Right-left distance:

 Small distance

 Big distance

Right-left spatial position:

 Hands crossed

 Hands interlinked

 One hand inside the other

 Left in front of right

 Right in front of left

g/s — Right higher than left

s/d — Left higher than right

Finger state:

Finger closed

Finger straight

Finger bent

Finger bent at palm knuckles

Finger contact:

Thumb with middle finger

Thumb with little finger

Thumb with index finger

Thumb with ring finger

Index finger with middle finger

Handshape:
(graphics are taken from [15])

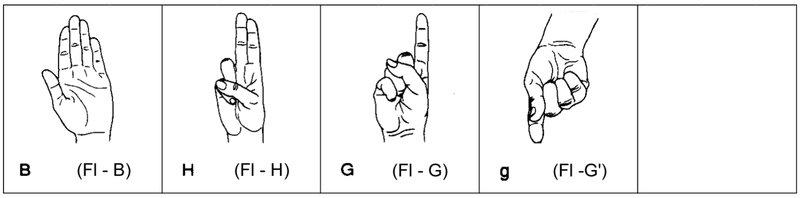

Figure A.1: Flat shaped.

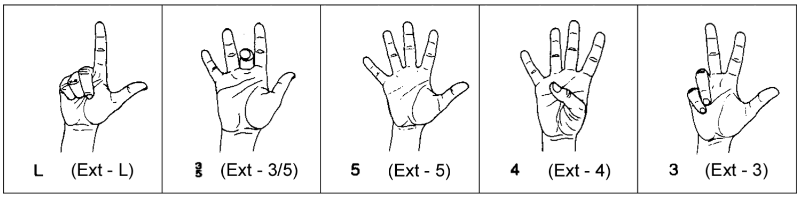

Figure A.2: Extensions 1/2.

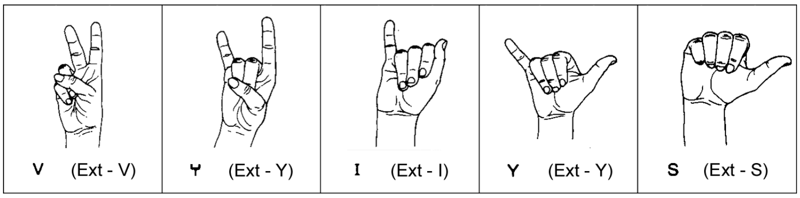

Figure A.3: Extensions 2/2.

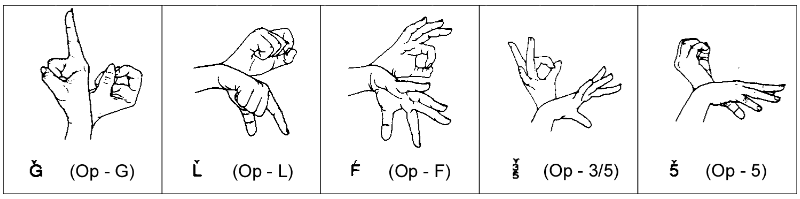

Figure A.4: Opening 1/2

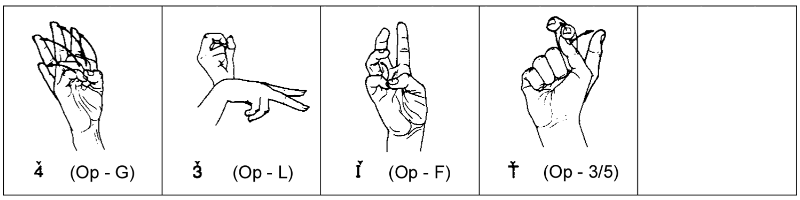

Figure A.5: Opening 2/2

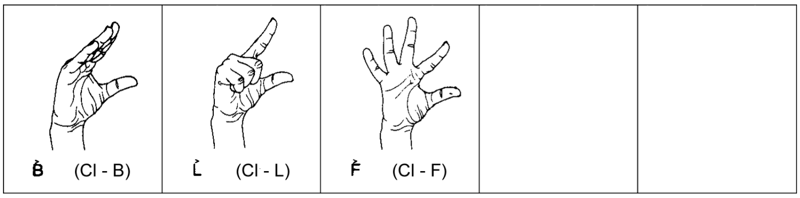

Figure A.6: Closing 1/2.

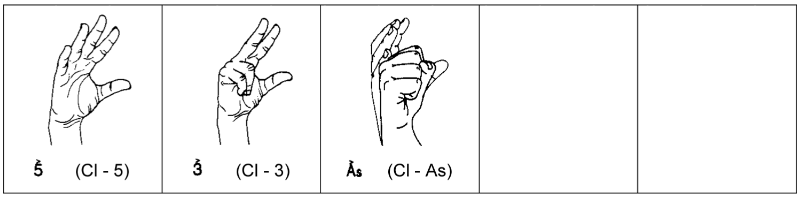

Figure A.7: Closing 2/2.

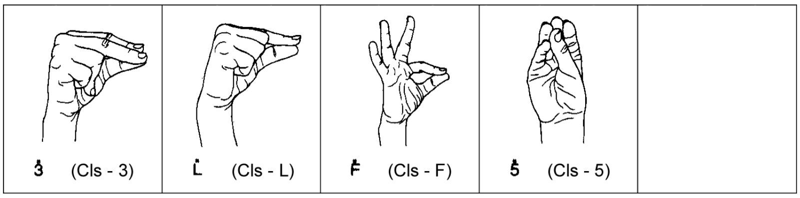

Figure A.8: Closed.

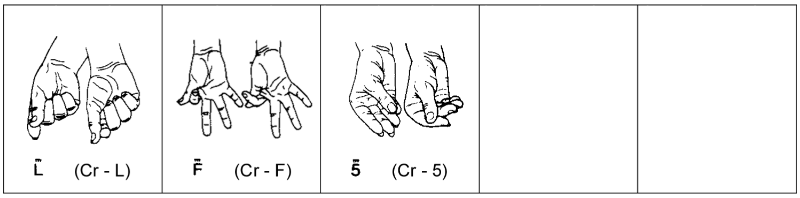

Figure A.9: Crumblinglike.

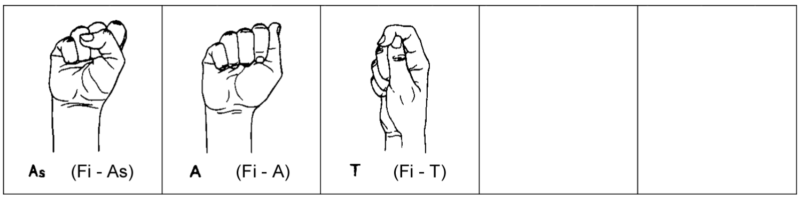

Figure A.10: Closed fists.

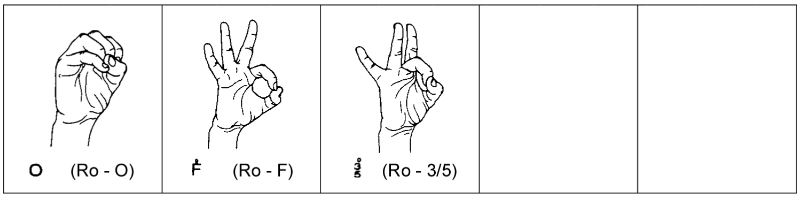

Figure A.11: Round shaped.

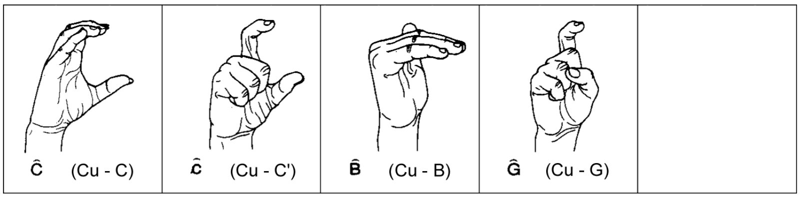

Figure A.12: Curved 1/2.

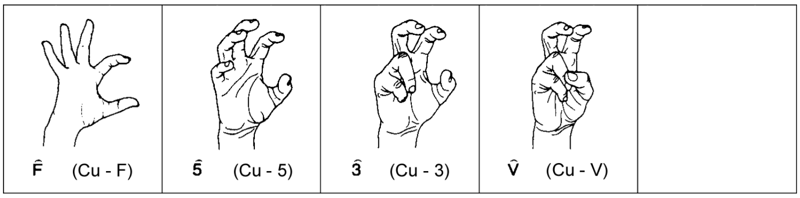

Figure A.13: Curved 2/2.

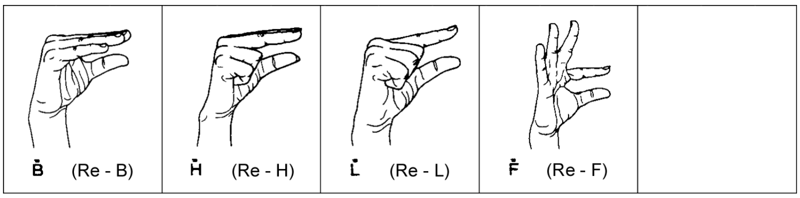

Figure A.14: Rectangular.

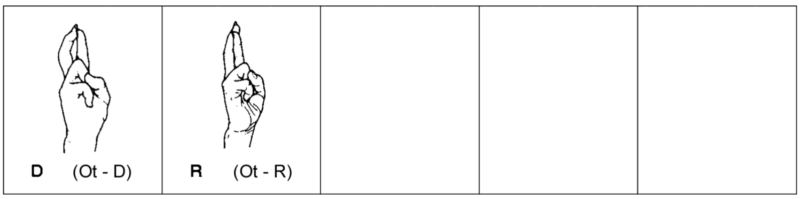

Figure A.15: Others.

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