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Abstract:

This paper presents a French national multidisciplinary Project (LS Script), whose aim is the elaboration of a graphical form for French Sign Language (LSF). It includes the presentation of three of the steps that have been achieved or undertaken up to now:

- Assessing the results of a qualitative survey, of practices and expectations of LSF signers relative to a graphical representation of their language (LSF). This investigation allows us to define the functions expected from the projected formalism, so as to determine the type of encoding to be conceived.
- Setting up the theoretical and methodological grounds we establish in order to explore the lowest structural level in LSF, so as to determine a viable minimal graphical unit for the formalism to be conceived. This exploration is grounding in Cuxac's hypothesis of a morphemic rather than phonemic organization of this lowest level.
- Developing digitized representations of signs, of signing space and of the signer's face to allow the analysis of a video corpus, aid in transcription, encoding of the formalization, writing editors and reading assistance with a signing avatar and the development of educational applications in schooling, in distance communication in LSF and in the Internet use.

Sign Language (SL) in Graphical Form: Methodology, modellisation and representations for gestural communication

The multidisciplinary project presented here[1] aims at creating a graphical form for French sign language (LSF). The key question that motivates this project is the following: for deaf citizens of literate societies, whose language is an institutionalised SL, what can fulfil cognitive, social, and pedagogical functions that the written form of language is used to fulfil? The main specificity of our programme is that it is grounding in a preliminary qualitative investigation of the population concerned. At the same time, allowing written communication

[1] The work presented was carried out in two successive frameworks: a project subsidized by the DGLFLF, Ministry of Culture and Communication (2003-2005); a project RIAM, *LS Script* (2005-2007, Minister delegated to research). They associate researchers in humanities and social sciences (linguistics, psycholinguistics and sociology), researchers in computer science (IRIT-TCI Toulouse 3 and LIMSI Orsay), the IRIS institute of Toulouse and the WebSourd company of Toulouse, provider of services for the deaf and new technologies.

on the basis of a gestural language opens the way for numerous interactive applications based on the gesture.
A variety of notation systems for SL have been elaborated[2]. However 1/ for the vast majority, these are transcription systems dedicated only to research and not systems aiming at permitting written exchanges and besides, 2/ these are systems conceived starting from de-contextualised lexical signs (outside discourse). In this sense, they do not take into consideration what seem to be the most striking structural specificity of SL: the multi-linear use of corporal parameters which are specialised linguistically (gaze, facial expressions, facial and corporal movements, hands); massive iconicity; the relevant utilisation of space and of space-time and the crucial modifications which spatialization induces in the form of signs[3].
This paper presents three of the steps which have already been completed or undertaken:

1. The results of a qualitative survey, of practices and expectations of LSF signers relative to a graphical representation of their language. Such an inventory, which aims at defining the functions expected from a graphical system, plays an essential role in determining the encoding to be conceived (notation of the form and/or notation of the morphemo-graphical type).
2. In order to determine the choices to be made in the elaboration of the structural bases for a graphical formalism, the exploration of the lowest structural level in LSF; the crucial point here is to choose a viable minimal graphical unit for the projected formalism.
3. The refinement of computer models and digitised representations of signs, of signing space and of signer's face, allowing for:
    - the analysis of a video corpus and aid in transcription,
    - the encoding of the new formalism (Unicode) and assistance in its editing (writing editors),
    - assistance in reading (through the animation of a virtual signing humanoid),
    - the development of educational applications in schooling, in distance communication in LSF and in the Internet use.

1. Which written forms are adequate to French Sign Language (LSF)? The Results of a qualitative survey of LSF signers

There are two main motivations for our choice of basing our enterprise on a qualitative survey. The first of these is moral and political: how can we imagine providing a language with a written form without from the outset involving its community of speakers? Our other motivation is theoretical. Any system of notation is based on the integration of hypotheses concerning what structures language but also on formal choices and implicit choices that depend on the potential uses and potential users of the system: it is essential to define these. Beyond a preliminary investigation into the notion that the Deaf we encountered have of writing in general, we tried to ascertain their relationship to their actual uses and practices of graphical representation, and to evaluate with them their expectations in this matter. Our investigation was meant to be open, prospective and not only limited to graphics in a strict sense; we include indeed an analysis of the role of video, and new visual technologies functioning as written forms, and explore the possible interest of providing LSF with a specific written form.

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[2] For an inventory, see (Miller, 1994 and 2001) and for a critique (Pizzuto & Pietrandrea 2001)
[3] See (Boutet & Garcia 2003)

1.1. Methodology

In order to carry out a thorough investigation on graphical representations, uses and practices, individual, semi-guided interviews was necessary. We carried out 31 two-hour interviews. Aiming to better understand the actual diversity in terms of geographical location, profession, age and personal history, we have nevertheless chosen to prefer the milieu of teaching, the teaching of and with LSF, where the subject is crucial. In a society where teaching remains mainly structured by written forms, how can we imagine generalising the teaching of and with LSF without asking what will function as a written form for this language? As regards teaching in schools, our study being prospective, we have also given greater place to bilingual structures of education (these structures represent only 1% of the educative structures for the deaf children today). The choices made imply that this survey does not claim to take into account the situation of all the deaf of France.

The persons we encountered are adult deaf signers, aged 24 to 59. With the exception of one person who was schooled from primary school onward in bilingual structures, the interviewees were in specialised schools and /or in integration, and therefore had an "oralist type" of schooling. This reflects the educational situation of the deaf in France. The table below shows the distribution of the persons encountered, according to their profession; they were natives of various French cities: Paris (12), Toulouse (10), Bayonne (2), Poitiers (1), Bordeaux (1), Champ sur Marne (1), Grenoble (1) et Suresnes (1).

Teachers of LSF in associations	4
Teachers of LSF in schools	2
Teachers in LSF (primary and secondary)	6
University staff	4
Students	5
Actors and directors	4
Researchers	1
Others	4

We set the number of interviewers at 5, all hearing and familiar with the Deaf community. The fact that these interviewers were hearing and not deaf results from the fact that up to now no deaf person is both trained in the problems under study and in conducting such interviews. We adopted the framework of a three-person team, interviewer, interviewee and interpreter. The exchange was recorded both on audiotape and on videotape. The interviews were transcribed into written French in their entirety. We will show here only some of the main results of the survey, to the extent that they directly determined the orientation to be given to our research.

1.2. Practices and Needs

Our first major observation was that alongside written French, there are numerous specific graphical practices, i.e., which aim at a notation of LSF, independently of any degree of mastery of written French. These are practices maintained for oneself, or between deaf persons. The most frequent case is, even if one masters written French, a specific use of this form that the interviewees designated as equivalent either to *LSF-French* or to written *LSF*: the ordered alignment of French words, according to them, in the syntax of LSF. The weaker the mastery of French, the more this LSF-French is mixed with drawings, up to the point where it is essentially composed of drawings and other graphical symbols. This process can lead to the perfecting of completely original systems, from which all "*word-signs*" are absent. However, we will henceforth insist on situations where the deaf we encountered have

recourse to these specific practices, even when they have mastered written French - since, as they say, it does not satisfy their needs.
It is firstly in situations where one has recourse to a graphical support to aid in the construction of a reflection, especially when this has to lead to a production in SL (conferences, appointments). One then either utilises only written French but limiting oneself to a list of "*keywords*" or "*key phrases*", presented as simple "*reminders*" referring more to ideas conceived in LSF than to French. Therefore, the most often and especially for those who have little or no mastery of written French, one has recourse to the continuum evoked above which ranges from "*LSF-French*" to mere idiosyncratic graphical symbolisation. In any case however, as the conception functions in LSF, this situation is presented as one of the most unsatisfactory or most frustrating —while the use of the written word as support for a cognitive elaboration leads back to one of the key functions of any written form of language.
Another situation that becomes a problem is that of a support for an oral presentation in LSF, the equivalent of written notes for a hearing lecturer. The particular difficulty here is that even if one feels at ease in written French, its utilisation as a support perturbs the fluency of production in LSF and gives rise to a production of 'signed' French. Here again, many solutions can be found, but are always described as less than satisfying. The two problems that we have just evoked crop up, according to the teachers we encountered, in LSF teaching in a school setting, when the pupils have to prepare (in class or at home) then sign a production in LSF in front of the camera for exercises of auto-correction or for evaluation (the composition of hearing pupils).
We will evoke two other cases which pose a problem. The first is note-taking in a course, a conference or a meeting in LSF; all recourse to French is often said to be inadequate and worse if one wants to conserve a specific formulation in LSF. There is the case, moreover, in which one creates in LSF a literary or artistic production and where one wants to a graphical expression which will surely allow it to be memorised and which will allow it to be re-worked in detail —and for which video is not sufficiently flexible. This is a case that could have given rise to the most systematic graphical inventions, even if, their use is usually limited to a small number of persons. A similar situation, just as rich in idiosyncratic graphical practices, is encountered by actors and directors for the graphical adaptation to LSF of a text in written French, but also of their personal interpretation, whether they want to memorise it or to re-work it.
According to the interviewees, however, a part of the functions that writing fulfils specifically for the language of which it is the written form are, for SL, already fulfilled - or could be - by video and the new visual technologies. A majority as "the written form of LSF" which contribute to considers these: preservation and archiving, pedagogical support for teaching (in) LSF (feed-back for a production, support and record of lessons, support for evaluations) support for producing norms of the language (discourse referents, video dictionaries), and as a means of dissemination. For a few, the rapidity of technological progress allows them to predict that certain present limitations of video — difficulty of use, especially for editing and selection of data for a document— will soon be resolved.
However, as the majority of interviewees have said, certain limits will not be resolved. The first is linked to access to data banks (research engines). The predicted potential in the medium term regarding digital image recognition (movement and form) are along way from being the economical equivalent to those representing the expression of query *via* a specific graphical representation of the language data sought. More fundamentally however, for the majority of persons encountered, video presents intrinsic limitations which prevent it from specifically playing the role of support for the elaboration of a reflection, and for which as we have seen, written French, even when mastered, is unsatisfactory. This is due firstly to the maintaining of the visible physical presence of the 'speaker': video, by this very fact, remains

bound to the face to face communication; it forbids, above all, the distancing that the written form authorises, *a fortiori* when it's a matter of one's own image. It is secondly due to the fact that, in production as in "play", because video as it plays does not allow for the apprehension of what is being recorded and of what has already been recorded — a simultaneity which is the very basis for the potentials of "graphical reasoning".

1.3. Implications

It is above all in teaching that difficulties linked to the absence of a specific written form for LSF are to be found in great number. We mentioned above the problems encountered in the teaching of LSF to deaf children, regarding the conception, then the production in front of the camera, of a "composition" in LSF. There are also the difficulties evoked by teachers of written French in LSF, who are tied, in their view, to an imbalance between a basically oral language (without its own written form), SL, and French language, which disposes of two registers. They note thus a double difficulty: first, when they want to work starting from a creation by the children done in LSF (the classic stage of the search for ideas) and to go towards written French, the necessity of passing in any case by a sort of graphical formalisation of the content in the SL produced, which is "slapped together" *ad hoc* and which does not satisfy them. Then there is, for the study (in LSF, the language of instruction) of a French text, the feeling that they have, by sticking to the translation of the content into LSF, of missing what defines a written text as such.
These various points confirm the interest in elaborating a system that allows for written production in LSF. They make it possible, moreover, to specify the foreseeable options according to the desired functions. Our survey bears out the fact that, for the most expected functions, especially those of support for cognitive elaboration, for a search for ideas, for note taking, for the formulation of a query in a database, one may conceive a type of morphemo-graphic or at least mixed notation (morpho-phonographical).

2. Database of standard signs with morpho-phonetic structuring in French sign language (LSF)

2.1. Problem

As we said below, a preliminary necessity for this project of graphical formalisation is to determine the minimal graphemic units and to choose the nature of encoding (Garcia & Boutet 2003, 2006). We proceed on the basis of Cuxac's theoretical hypothesis (Cuxac 2000, 2004) which favours a morphemic rather than a phonemic organisation at the lowest level in LSF and allows a morphemic composition of both *standard* signs (STS) and structures said to be *of high iconicity* (SGI) —"productive signs"—, these ones including "Personal Transfers" (role-play), "Transfers of size and of form", and "Transfers of situation". The systematic exploration of this hypothesis over the LSF lexicon currently on record (Girod *et al* 1997) will make it possible to establish low-level morphemic components, to assess their productivity and to set out some rules for their compositional potential. Finally, it allows to test the validity of a strictly parametrical approach and moreover to evaluate the merits of a graphical formalisation which is at least partially founded on a notation of the signified.
The implications of this project are of two different orders:
1/ It will serve to find an alternative to current notation systems for SL. These systems encode the mere visual aspect of sub-lexical parametric units (configuration, orientation, location, movement, ± contact, ± facial expression), that is to say the graphical principle they use is based on that which structures alphabetical systems invented for vocal languages.
Beyond the acknowledged limits of present systems for the notation of discursive phenomena in SL, the interest of identifying a low-level morphemic economy is:

a/ to take an account of the structural specificity of SL, especially of HIS and their permanent interaction in discourse with the STS. In our theoretical framework STS and HIS use a common set of morphemes: thus we can take the inventory of graphical units that are transversal to both types of structures and also graphically take stock of numerous discursive phenomena of co-referentiality and of the differentiated utilisation of space (metrical egocentric space, allocentric and topological spaces);
b/ to provide an answer to the recurrent problem of the cumbersomeness of existing notation (more than 600 graphic symbols for *Sign Writing*[4]): a graphical encoding that gives direct access to meaning (morphemo-graphic notation), at least for part of the notation, inducing a lower cognitive cost.

2/ It will corroborate Cuxac's hypothesis through a formalisation of the low-level morphemic stratification. As Cuxac's model grounds in the assumption of a morpho-phonetic structure (form-meaning constants) anchored in the perceptivo-practical (anthropological structuring), this formalisation should in due time furnish a solid basis for comparison with other SL and allow an evaluation of the part to be attributed to cultural specificity.

2.2. Methodology

A database was created from 4000 STS currently listed, and checked by native signers. The analysis of this corpus focused on configuration and location parameters, for which the morphemic values were inventoried, sign by sign, and on the movement relative to the principal components of each configuration. Regarding the configuration, the approach was carried out using configurations classified in (Girod 1997) and by distinguishing, on the basis of the inventory of configurations already established by Cuxac for HIS (Cuxac 2000, 97-130), the configurations attested both in HIS and in STS, and those that exist only in STS. Due to the lack of any pre-existing classification of types of location, the analysis for this parameter follows an *ad hoc* logic. The direction of movement was described according to salient characteristics of the configuration (planes, axis, points) and can be re-contextualized for each configuration. Generally speaking, for this parameter and for the orientation parameter, the description is made relatively to a position and/or to a segment, including the other hand, thus offering the possibility of moving the frame of reference so as to better understand the different utilisations of space.

The main methodological difficulty is due to the validation of morphemic values retained and to their labelling. There were three types of validation of those units of meaning: 1/ the internal economy of morphemic networks that were identified; 2/ the productivity of these form-meaning constants (for *one* meaning reposing on several parameters, preponderant parametric form is retained for graphical encoding) and their capacity to explain neologisms; and 3/ the feed-back of native signers.

2.3. First Outcome

For the parameters under study, the analysis confirms the existence of an optimised economy of morphemic values (2 to 4 per parametric unit) and the coincidence of the most productive of them with those values attested in the HIS. At the same time, the study allowed us to identify, for a single parametric unit attested in both types of structures, which morphemic values were specific to STS. Our analysis also brings out a stratified organisation: around a large morphemic value we find an organisation in families, the signs of each family being linked together by the exploitation of a particular semantic specialisation of this morphemic value. As regards location, the entry by morphemic value furnishes criteria of classification and points up interdependencies with the choice of configurations (which is particularly the

[4] Sign Writing System, (Sutton 1999)

case of locations on the body). A graphic economy can therefore be achieved at this level. Moreover, the analysis brings out a model for a semantic segmentation of the body's surface and of the signing space. It displays numerous concordances with semantically predetermined areas used in the spatialization of certain syntactic relations (hypothesis, time, choice of *loci*) *cf.* (Engberg-Pedersen 1993), shedding new light on the relations between lexical and grammatical levels in SL. The relative direction of movement reveals a great economy of means in the structure of STS and provides a strong link between the configuration and types of movement. This leads to a very restricted ensemble of items which can be used for notation.
In this way, morphemic structuring has been found to be largely confirmed. The existence of several values for a single configuration requires one to consider either an infra-parametric mode of composition (Boutet 2005), or a crystallised deposit on a particular parametric value of a previous composition (diachrony, see Bonnal 2005). For these two options, to merely analyse the parametric level cannot exhaust the resources of elaboration of meaning in LSF. Inter-parametric links, especially between configuration and movement parameters, argue in favour of a consideration of an articular level of production that would be more phonetic than phonemic. However, a certain economy of graphemic encoding is henceforth possible.

3. Sign language processing: models, representations, tools for video analysis, for signing avatars and for communication

This section is related to the computer science side of the project. Our aim is to study the basis needed for the design of educational tools. These tools aim at facilitating the writing and the reading of utterances in LSF.
As said earlier, the notations will be based on visual aspects and on meaning aspects. This implies bottlenecks for computing modelling at several levels: At the lower one, for modelling the constitutive parameters of the gestural units, and at the higher level, for modelling utterance representations of any kind, including those of high iconicity described by Cuxac (Cuxac 2000, 2004).
These models must include all kind of linguistic phenomenon needed for writing or reading, including manual and non manual representation, spatio-temporal rules, and cognitive knowledge. In this section, we present two studies related to the utterance level: the first one is related to the modelling of spatial relations in LSF, and the second is related to the modelling of the construction of the narration scene.

3.1. Modelling of spatial relations

Sign languages allow us to show in space what is said, as for example spatialised semantic relations. These relations can be of different kinds. They can be *static*, like in “the cat is in the car”, or *cinematic*, when we can distinguish initial and final situations, like in “the cat jump into the car”. When the action is controlled by one of the protagonists of the situation, like in “I put the cat in the car”, the relation is *dynamic*. Depending on the type of the relation, more or less movement will be present in the hand, arm and body of the signer. For example, in the case of a dynamic situation, the signer will add a body movement to the realisation of the predicate sequence of signs, to express the involvement of one of the protagonists.
The modelling of such kind of properties is based on cognitive grammars, which are based on abstract schemes anchored on mental representations build from the experiences of perception and action on the world.
Our modelling is based on the model proposed by Fanch Lejeune for LSF (Lejeune 2002, 2001). The aspects we are taking into consideration in the model are:

- the preferential order of the gestural units, that will be represented as grammar rules,

- the selection of two locations in the signing space in order to show the relation,
- the use of gaze to instantiate locations or to refer to these locations,
- the use of proforms, which give a point of view on the entity or on the relation.

The formalism is based on a formal notation using typed operators and operands (Braffort 2005). Each scheme is associated to an operating sequence that allows us to generate a representative utterance.
For example, to represent a geographical relation between two locative entities, such as in the sentence shown in Figure X1, where the University Paris 8 is situated regarding Paris, we manipulate the following scheme,
<POINT(university) REP (IN(PROJ(FR(DET(LOC(Paris)))))))>
where 'university' is located by means of a pointing gesture (POINT operator) directed on e location in space related to the entity 'Paris' (REP relator), considered as a location (LOC operator), which is determined by its frontier (DET operator), which is the base of an oriented projection (PROJ operator) defining a new location, and the university is located in this new location (IN operator).

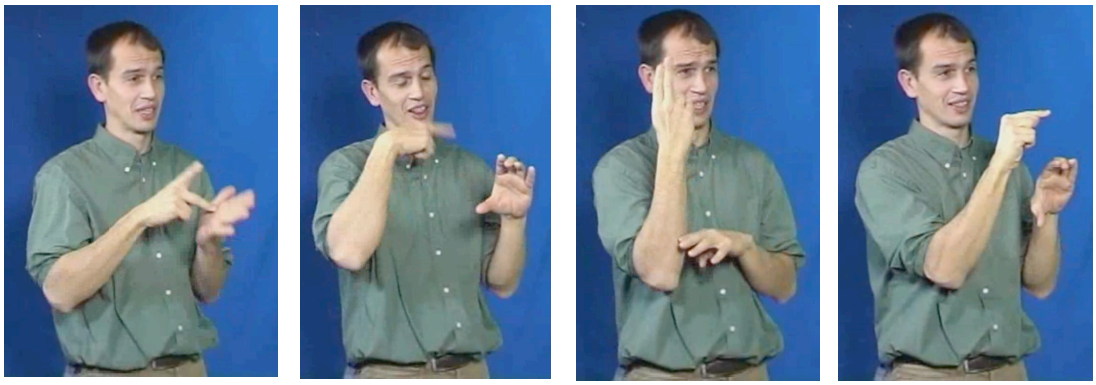

Fig. 1: LSF sentence "The Paris 8 university is situated regarding Paris" 1: $[PARIS]_{LSF}$, 2: Frontier of Paris, 3: $[UNIVERSITY]_{LSF}$, 4: spatial relation

This modelling is used to automatically generate a representative sentence performed by a signing avatar (see Fig. 2).

Fig. 2: *Elsi*, the LIMSI signing avatar

The computing system, not detailed here, is composed of several knowledge bases, about entities, geographic relations, and proforms. A representation of the signing space allows the various locations to be stored and used for proform locations and gaze direction. More details can be found in (Braffort 2005a, 2005b).

This study is a first step toward a more general modelling that will include other kind of representations, and a more sophisticate representation of the signing space, as the one proposed in the next section.

3.2. Modelling of the construction of the narration scene

The second study is related to the construction of the narration scene and the sequence of gestures produced to build the scene. The narration scene contains all the elements to which the signer and his addressee make reference. It is the framework for structuring discourse. Its modelling enables an image analysis system to anticipate and interpret visual events in linguistic terms and produce a syntactico-semantic description of the discourse. Conversely, a graphic editor interpreting this representation should allow us to generate the structural framework of an utterance produced by a signing avatar.
The proposed model is composed of two parts: the narration scene construction, and the gesture sequence used to update the scene.
The modeling of the narration scene is represented by a UML class diagram (Fig. 3) which shows the various concepts and their relations. The signing space is an oriented 3d volume around the signer. It is divided into sites, which contain referents. This volume is used to locate the entities.
Our model is an object hierarchy with a mechanism that insures consistency of the construction when a new entity is added. The representation allows all entities that may be further referenced in the discourse to be stored.

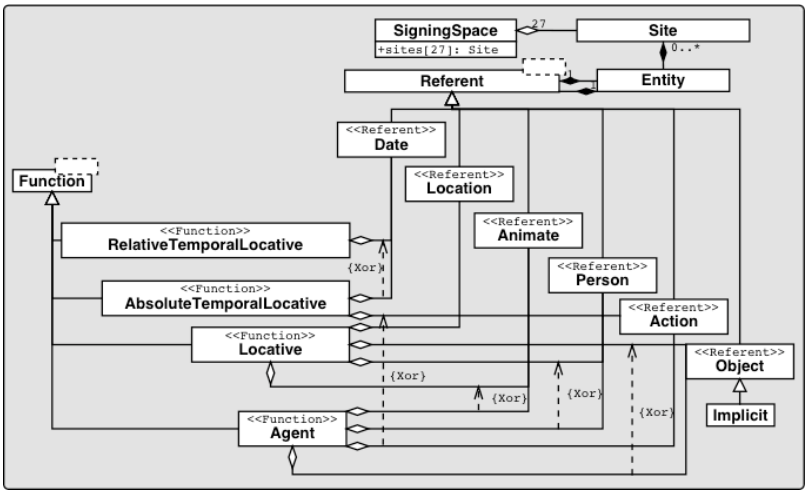

Fig. 3: UML class diagram of the semantic representation of the signing space

There is a set of sites; each site may contain entities. The entities have several functions: temporal, actions and spatial location. There are different kinds of entities, according to their potential functions:

- Date can be temporal relationship,
- Action can be an agent or temporal location,
- Animate can be implied in action or used to locate others agents,
- Location can only be used as locative.

Entities can be used in shift role (person) or not (object).
These kinds of entities are only defined by their potential function and not on a lexical categorization base.
The video (Fig. 4) shows an example, extracted from a LSF corpus of requests about a movie theatre program, with its signs to words translation. On the right, we have a symbolic 3d representation that is built with an interactive tool that implements our model. We can see

how entities are located in the signing space: Two locations (the city of Toulouse and the movie theatre), an “object” (the movie), a date, a person and an action (directional verbs), which links the person to the notion of movie. An internal XML representation keeps trace of this construction.
For automatic SL processing, we need a second model, a formal representation of sign language grammar that links the narration scene construction to the sequence of gestures used to add a new element in the scene.
This model represents our knowledge about the gestures that are used to create an entity of a given type at a given place in the narration scene, and about the aspects of the components that perform theses gestures, in a reduced context.
We use the description logic as formalism to represent this knowledge in computer.
The main concept is the notion of ACT (an ACtion Transforming the narration scene), a hierarchy that describes the creation of an entity in a given location by the mean of a gesture sequence associated with the corresponding time interval.
ACTS contains a gesture sequence for each kind of ACT and for each part of the sequence there are different ways to evoke the entity.
The gesture concept hierarchy consists in a description of signer’s body components used to evoke the entities.
Finally, time intervals are used for gesture synchronization by the mean of rules that defines their order in a sequence, based on the interval algebra.
Thus, if we want to automate the video analysis to help writing sign language, we can use image analysis system to verify the state of the component (head, hand…). If the predicted state is found, the creation of the entity is validated and is added in the narration scene description with the correct type.
These two studies are our first attempts into modeling of high-level knowledge to be integrated into future tools dedicated to writing and reading graphical form of LSF.
The proposed models should be compatible with both shape-based notation and morphemographic or morpho-phonographic notations.
The next steps of these studies include three levels of integration:

- integration of the two proposed models,
- integration with the lexical representation presented in section 3,
- connection with the future graphical form.

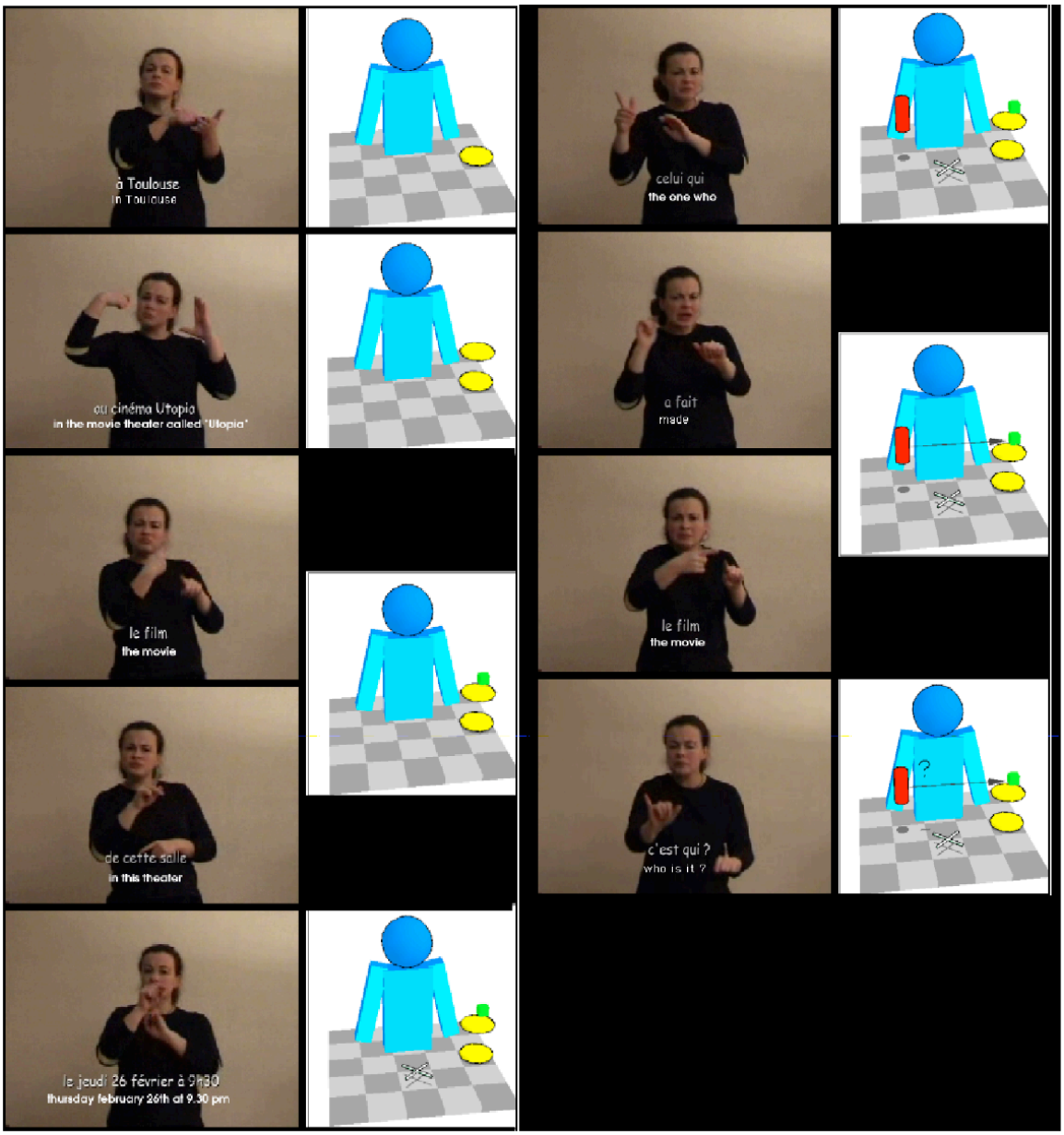

Fig. 4 : construction of the signing space during the realisation of a sentence.

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