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# PROCESSING OF SYMBOLIC MUSIC NOTATION VIA MULTIMODAL PERFORMANCE DATA: BRIAN FERNEYHOUGH'S *LEMMA-ICON-EPIGRAM* FOR SOLO PIANO, PHASE 1

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## ABSTRACT

In the “Performance Notes” to his formidable solo piano work *Lemma-Icon-Epigram*, British composer Brian Ferneyhough proposes a top-down learning strategy. Its first phase would consist in an “overview of gestural patterning”, before delving into the notorious rhythmic intricacies of this most complex notation. In the current paper, we propose a methodology for inferring such patterning from multimodal performance data. In particular, we have a) conducted qualitative analysis of the correlations between the performance data (an audio recording, 12-axis acceleration and gyroscope signals captured by inertial sensors, kinect video and MIDI) and the implicit annotation of pitch during a sight-reading performance; b) observed and documented the correspondence between patterns in the gestural signals and patterns in the score annotations and c) produced joint tablature-like representations, which inscribe the gestural patterning back into the notation, while reducing the pitch material by 70-80% of the original. In addition, we have incorporated this representation in videos and interactive multimodal tablatures via the use of INScore. Our work draws from recent studies in the fields of gesture modelling and interaction. It extends the authors’ previous work on an embodied model of navigation of complex notation and on an application for offline and real-time gestural control of complex notation by the name GesTCom (Gesture Cutting through Textual Complexity). Future prospects include the probabilistic modelling of gesture-to-notation mappings, towards the design of interactive systems which learn along with the performer while cutting through textual complexity.

## 1. INTRODUCTION

In the “Performance Notes” of the published musical score of *Lemma-Icon-Epigram* for solo piano, Brian Ferneyhough states:

“An adequate interpretation of this work presupposes three distinct learning processes: (1) an overview of the

(deliberately relatively direct) gestural patterning without regard to exactitude of detail in respect of rhythm; (2) a ‘de-learning’ in which the global structures are abandoned in favour of a concentration upon the rhythmic and expressive import of each individual note (as if the composition were an example of ‘punctualistic’ music); (3) the progressive reconstruction of the various gestural units established at the outset on the basis of experience gained during the above two stages of preparation” [1].

The proposed top-down approach to learning is neither unique to this particular work, nor uncommon in similar repertoire: Both the composer’s earlier remarks in his *Collected Writings* [2] concerning prioritisation in learning, as well as reports in [3], [4] of performers specialising in complex contemporary piano music, privilege a pragmatic grasping of global structures of the work in the beginning of the learning trajectory, before navigating the fine detail and stratifying it in a personalised manner.

Setting aside for the moment the question of whether Ferneyhough’s “gestural patterning” refers to physical or musical gestures, we make two hypotheses:

- a) That his tripartite learning scheme can be externalised and represented as a processing of the symbolic notation on the basis of and by means of multimodal data and their correlations. This hypothesis is based on findings in the field of *embodied and extended cognition* [5], [6].
- b) That the representation of pitch information in the first phase of learning can be modelled in relation to the horizontal movement of the hands along the keyboard space and particularly correlated to gestural signals captured by inertial sensors.

For the rest of this paper, we will review relevant work in the fields of gesture modelling and interaction; we will present our methodology and findings; we will propose derivative representations and interactive tablatures, as well as future prospects for the probabilistic modelling of gesture-to-notation mappings.

## 2. RELATED WORK

Our work on the creation of gesture-to-notation mappings and interactive systems derives at large from previous research on gesture modelling and gesture-to-sound mappings employing machine learning techniques. Bevilacqua *et al.* proposed in [7] a Hidden Markov Models (HMM) methodology defined as *gesture following*: Incoming gestural features, modelled as mul-

tidimensional temporal profiles, are compared in real time to templates stored during a *learning phase*. This is the first step towards implicit or explicit mappings to sound, during a subsequent phase of *following*. Caramiaux has further proposed in [8] a segmental approach to this HMM methodology for the segmentation and parsing of clarinetist ancillary gestures. In this instance, gestural features are considered as temporal and gestural segments, compared to dictionaries of *primitive shapes*, constituting prior knowledge and opening-up the way for higher-order, syntax-like modelling. Françoise has addressed the problem of temporal multidimensionality and computational limitations of the previous models through the employment of Hierarchical HMM and Dynamic Bayesian Networks [9], while addressing also multimodal modelling (simultaneous modelling of movement and sound as opposed to modelling of movement alone) and Mapping-by-Demonstration (MbD) techniques [10] (whereby the end-user controls the process of machine learning interactively). He has also proposed a lower-order syntactical paradigm for gesture-to-sound mapping: a “gesture envelope” of Preparation-Attack-Sustain-Release (referred to as PASR from now on, after the classic ADSR sound envelope paradigm). [11]

Basic ideas from this corpus of work that proved influential, as shown in detail later, are: a) Template alignment (that is alignment between a stored template / dictionary of primitive shapes and an incoming data-flow): In our case, as will be explicated in 3.4, implicit annotation constitutes the template to which gestural features are compared; b) low- and high-order segmentation and syntax (from a PASR model to Attack-Displacement envelopes and to the gradual reduction of pitch material in 3.3 and 3.5 respectively); c) performance-oriented learning, as influenced by MbD; and d) hierarchical and segmental layering, evident in the concept of “embodied layers” (3.2).

These models are currently being employed in a variety of applications, including the performing arts, audio industry, sound design, gaming and rehabilitation with auditory feedback. For an overview of those, please visit <http://ismm.ircam.fr/>. A notable application was the “augmented violin” project [12], where those models were employed in conjunction with composed music and notation. Nevertheless, many more studies are required to fully understand how a musician’s movement can be modelled in a learning situation, as well as the complex relationships between gesture and notations.

Exhibiting the potential for gesture-to-notation mappings, following up from the paradigms of gesture-to-sound ones exhibited above, is one of the objectives of this paper. The other objective is to lay the foundation for the probabilistic modelling of notation according to gesture.

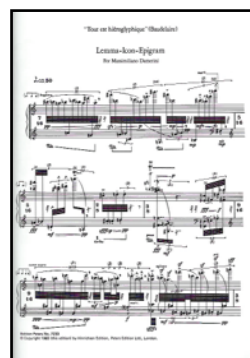
### 3. METHODOLOGY

Our methodology for the current study of the correlation between multimodal performance data and an implicit annotation of the score of *Lemma-Icon-Epigram* can be summarised as follows:

1. Sight-reading performance of the first page of *Lemma-Icon-Epigram* (fig.2) and recording of

multimodal data {audio, 12-axis gestural signals, kinect video, MIDI} as in fig. 3.

2. Representation of the implicit performative annotation of symbolic notation during the sight-reading performance: Embodied layers {fingers, grasps, arms} as in fig.4a. This representation constitutes prior knowledge.
3. Comparison of recorded gestural signals to the recorded audio and video and annotation accordingly, as in fig. 5. At a later stage, information is extracted from the gestural signals alone (and just confirmed from the video and audio).
4. Comparison of the annotation of gestural signals in 3. to the implicit annotation in 2., as transferred in the MIDI piano-roll: fig. 6.
5. Return to the symbolic notation: Transcription of the MIDI piano-roll representation into a reduced proportional representation of pitch in space: fig.7. Annotation of fig.7 according to the annotation of the gestural signals: Gradual reduction of the amount of pitch information and inscription of gestural patterning as in fig. 8.
6. Comparison of 5. to the original symbolic notation: fig. 9.

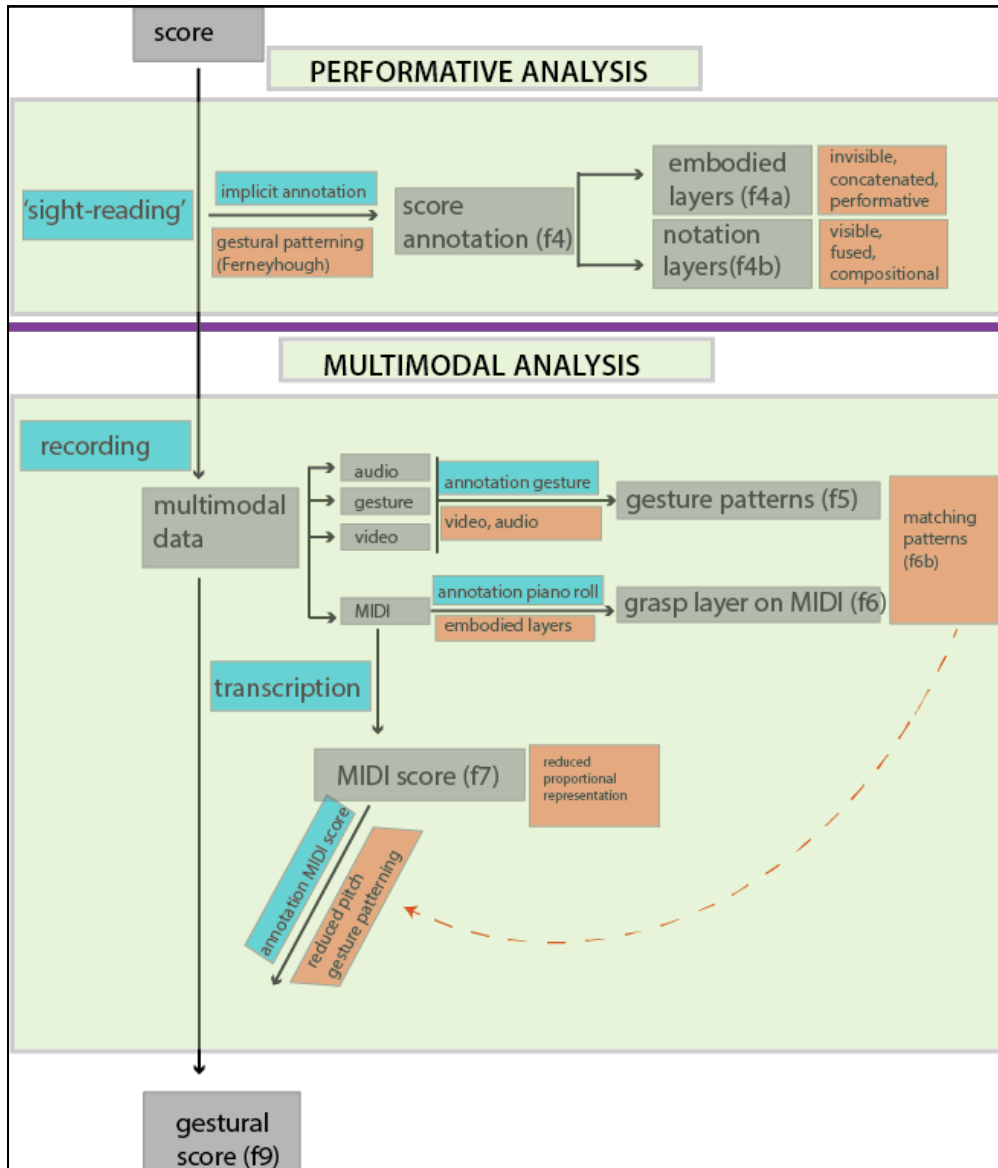


**Figure 2.** Brian Ferneyhough, *Lemma-Icon-Epigram*, p.1, original score. Reproduced with kind permission by Peters Edition.

The block diagram in fig.1 presents this methodology. A purple horizontal line represents the transparent border between the traditional approach to learning and its extension into our current approach via the use of recorded multimodal data. We remind that both strategies are tailored after Ferneyhough’s top-down learning model and refer to the first phase of “global gestural patterning”. Let us now elaborate on each of these steps.

#### 3.1 Sight-reading and recording of multimodal data

The term ‘sight-reading’ should not be confused with the literal use of the term, as in the classical music world - especially in the fields of opera coaching or chamber music, whereby training and ability ensure a sufficiently satisfying performance of all notated parameters without prior knowledge of the text. In our case, ‘sight-reading’ signifies a performance in the beginning of the learning trajectory, which prioritises an “overview of gestural



**Figure 1.** Methodology for the processing of symbolic notation through performance data. The input is the original score, output is a “gestural score”.

patterning” (Ferneyhough) rather than precise rhythmic and other detail. Furthermore, as already stated in the Introduction, we hypothesise that the sight-reading equals an implicit annotation of the musical score, representable as explicit annotations detailed in 3.2.

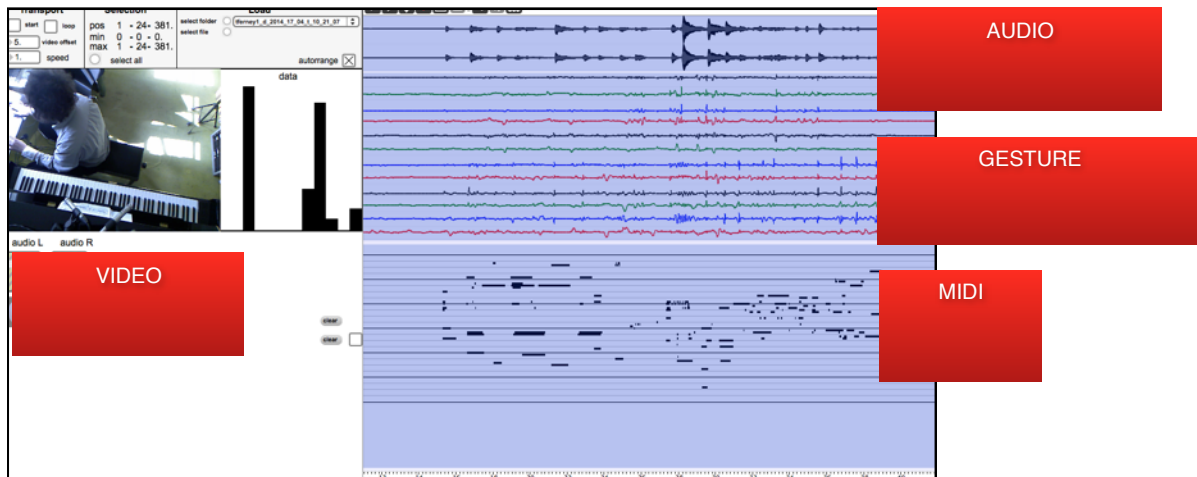
The first author’s performance for this case study took place on 18.04.2014 in the context of his Musical Research Residency at IRCAM. He performed and recorded three takes for each page of *Lemma-Icon-Epigram* in one day. His sight-reading prioritised ergonomic hand and arm movement in the keyboard space as well as pitch accuracy, while allowing only sporadic and spontaneous response to the parameters of rhythm, articulation and dynamics. A Yamaha upright Disklavier was used for the recording of MIDI information, while multimodal information included audio captured by two microphones, video captured by Kinect and movement data

captured by 3D accelerometers and 3-axis gyroscopes worn on both wrists. Fig. 2 shows the first page of the original score and fig. 3 the MAX/MSP patch used for the synchronisation of the data.

### 3.2 Representation of implicit annotation

Given the ambiguity of the term *gesture* in musical contexts, referring to both musical and physical, compositional and performative properties, the annotation may include two types of information:

- Notated “gestural patterning” elements such as pitch, articulation, rests, dynamics, pedal, beaming (fig. 4b). This information is visible, but also heterogeneous, multi-layered and fused. As an example, we have here only indicated the most salient gesture boundaries, reserving the rest of the gesture patterning elements for



**Figure 3.** MAX/MSP patch for the synchronisation of multimodal data, created by ISMM team / IRCAM

the second phase of refinement in the learning process.

- Physical gestural elements, such as fingerings, changes of hand position, arm movements, technical patterns. This sort of information is invisible, concatenated and embodied: it constitutes a *hidden layer* of the notation, albeit representable as in fig. 4a. In previous work [13] we have suggested a typology of physical gestural elements in relation to pitch, following up from ideas by the pianist György Sándor [14]. We have proposed a hierarchical ordering of notated pitch information in three embodied layers: fingers, hand-grasps and arm movements. The *finger layer* corresponds to traditional fingering and includes all notated pitch indexed with a number from one to five. Hand-grasps are by default defined as concatenations of pitch contained between fingers one and five. Depending on individual hand span, those pitch sets can be played simultaneously as chords or in succession as melody, potentially involving upper-arm participation and horizontal displacement. Consequently, the *grasp layer* can be effectively represented by the pitches assigned to fingers one and five, omitting the pitches corresponding to inner fingers. Similarly, hand displacement takes us to the *arm layer*, which can be defined as a concatenation of grasps. Its boundaries are defined by the succession of fingers one and five (in the case of outwards movements, that is displacement from the centre to the extremes of the keyboard for both hands) or by the succession of fingers five and one for movements from the extreme to the centre. As a result, the trajectories of hand transpositions or *arm layer* can be defined as a series of segments defined by digits one and five, depending on their directionality.

Please note that both the grasp and the arm layers may be defined as a succession of two-bit units of information: pairs of fingers one and five. Also: The segmental and hierarchical nature of those layers point directly to the gesture probabilistic models reviewed in section 2.

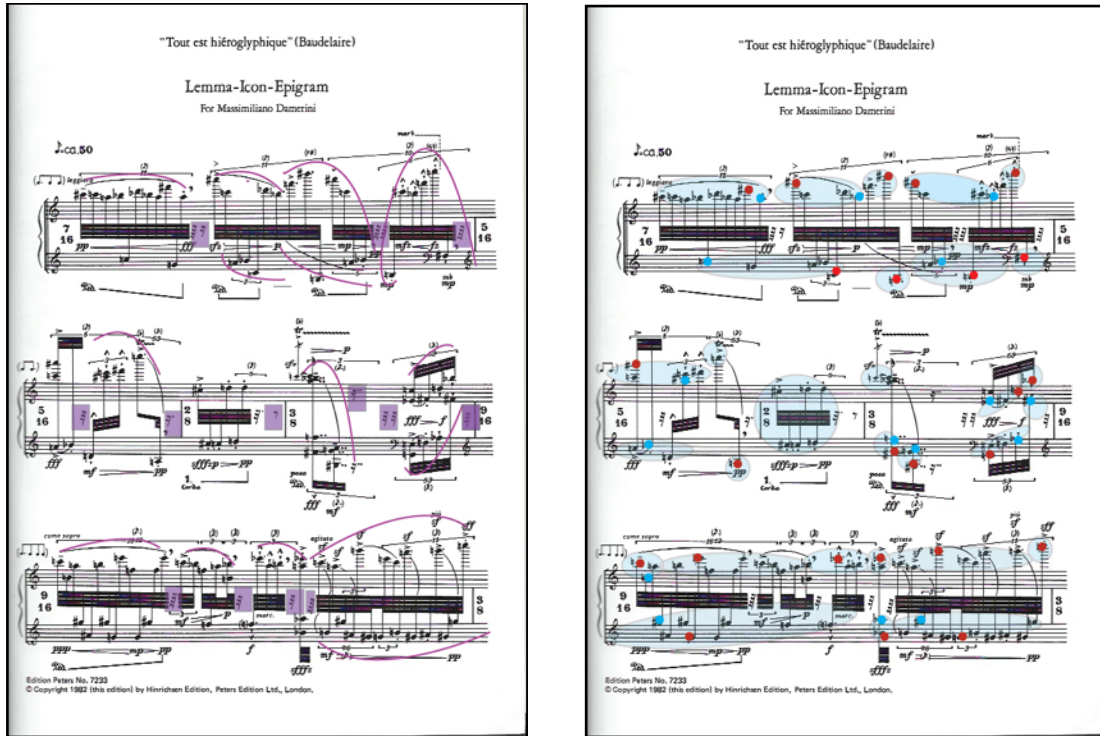
In fig. 4a the grasp layer is represented for both hands in the form of blue ellipses. There are no hand crossings, thus we keep the same colour for both hands. The highlighted noteheads indicate grasp boundaries: red note-

heads are employed for finger 5 and blue ones for finger 1 in both hands.

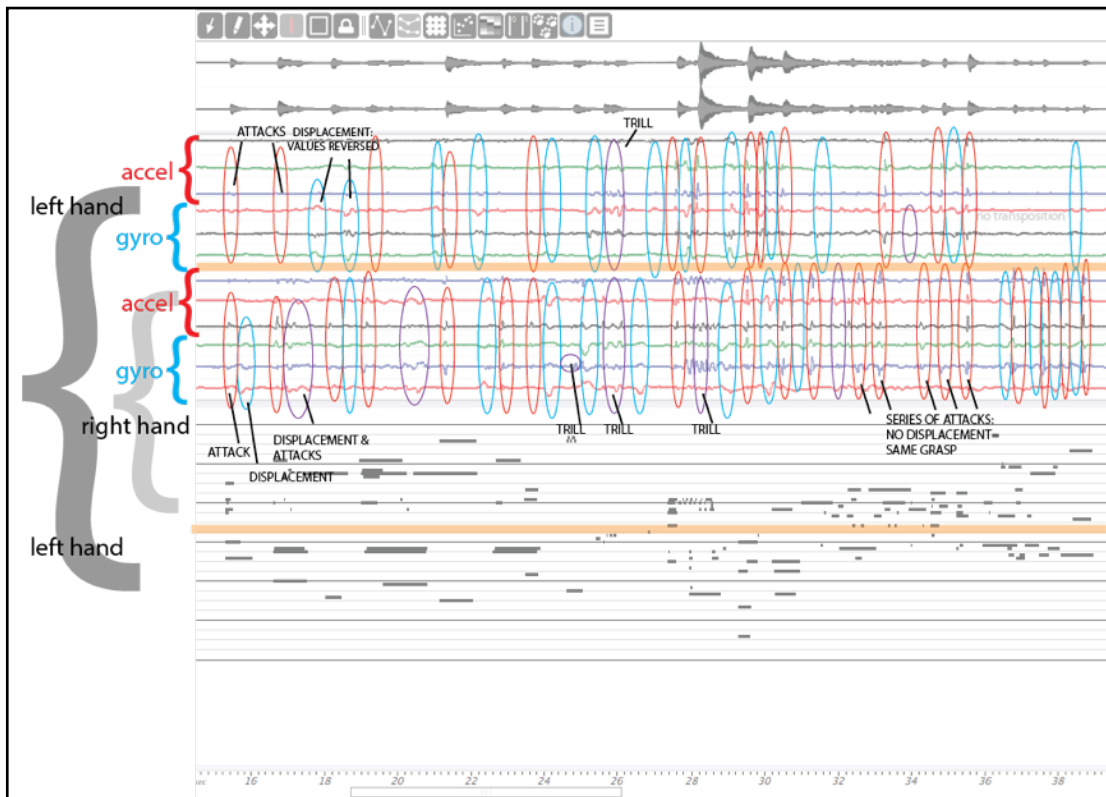
### 3.3 Comparison of gestural signals to recorded audio and video

The qualitative analysis of the multimodal data followed two phases: First, we observed the 12-axis gestural signals in relation to the audio signals and the kinect video. The results of our observations for page 1 are presented in fig. 5 and are detailed as follows.

- Accelerations related to attacks (clearly visible as amplitude peaks in the audio signals) are unequivocally discernible from accelerations related to the horizontal displacement of the hands. The first are marked with red ellipses, the latter with blue ellipses in the gestural signals of fig.5. Attack accelerations appear as instantaneous high amplitude peaks of the accelerometers and often the gyroscopes signals, while displacement accelerations are mainly captured by the gyroscopes as low amplitude and frequency peaks. Close comparison to the video reveals patterns related to the direction of the displacement, clearly marked also in fig. 5 (“values reversed”).
- Next to those two distinct types of events, attacks and displacements, we discern two hybrid events: trills (excitation visible in all six axis of the signal) and displacement with simultaneous attacks. Those events are more complex and more equally distributed between the accelerometers and the gyroscopes, and are indicated with purple ellipses.
- Observation of the sequence of the above-mentioned four types of events reveals two types of patterns: i) attacks / trills followed by displacements / displacements & attacks and ii) succession of attacks without intermediate displacements. The pattern ii) indicates that the events take place inside the boundaries of a single hand-grasp, while the pattern i) indicates changes of hand position and thus moving on to the arm layer.



**Figure 4.** Gestural patterning after articulation and rests (left, 4b); grasp layer indicated by blue ellipses for both hands, boundaries indicated with red blobs for fingers 5 and blue blobs for fingers 1 (right, 4a)



**Figure 5.** Annotation of 12-axis gestural signals according to video and audio

In short, the gestural signals offer us information about: The horizontal displacement of the hand (or not), its direction, its intensity and the possible presence of intermediate attacks. Higher-order segmentation and parsing will become clear in 3.5.

An interesting finding in the course of this annotation process was the gradual elimination of the need to confirm the information conveyed by the gestural signals through video and audio, the implications of which will be exposed later.

### 3.4 Comparison of annotated MIDI to annotated gesture

In the next phase, we transferred the implicit annotation of the score as in fig.4a to the MIDI piano-roll representation of our recording patch and compared it to the annotation of the gestural signals as in fig. 5. Our comparative study reveals an one-to-one correspondance between the two annotations: Attack gestures align perfectly with grasps and displacement gestures align with changes of position. The correspondance becomes clear in the matching patterns of blue arrows in fig. 6. The significance of this alignment is that the pianist's implicit knowledge is reflected in the objective gestural, audio and video data. The implication of this alignment is that the gestural data can be used for the modelling of incoming MIDI pitch information, without the need for implicit knowledge.

### 3.5 Return to symbolic notation

The next step was the automatic transcription of the MIDI piano-roll in symbolic notation, aiming at a new output score describing gesture. For this purpose, we used specially designed command-line tools developed by Dominique Fober and based on the Guido Engine<sup>1</sup>. The result is a reduced proportional representation of pitch in space as in fig. 7.

Further on, this representation is gradually annotated after the annotation of the gestural signals, in the form of a gradual reduction of the pitch material according to embodied layers' boundaries, that is fingers one and five, as follows in fig. 8a, b, c.

By keeping only the grasp boundaries (2-bit definition of grasp), we get a reduction in the amount of pitch as in fig. 8b.

The leap to the *arm layer*, defined as concatenation of grasps in a certain direction of movement, allows for a further elimination of one of the two grasp boundaries, depending on the direction of the movement. Grasps now are defined by only one note (upper note for movements outward, lower note for movements inward) and the patterns of hand transposition have an one-to-one correspondance to the gestural signals. The amount of pitch is further reduced.

A final reduction of the pitch information is possible, if we consider only the peaks of the arm trajectories, that is the boundaries of the horizontal arm movement. This representation does not fully coincide with the gestural signal, but can become visible at a high speed play-back

of the video. This representation corresponds to an exact 20% of the initial pitch content in fig. 7.

Eventually, the segmentation and parsing of gestures in higher-order syntactic units is possible as shown in Fig. 8e.

Interestingly enough, as shown in fig. 8, from the gestural signals' annotations and given a MIDI score we can infer a) the reduced amount of pitch material needed to describe gesture and b) the fingering of it. A consistent mapping between gestural signals and embodied MIDI representations is possible. Such a mapping would reduce the amount of pitch information by 70-80% for the first stage of the learning process.

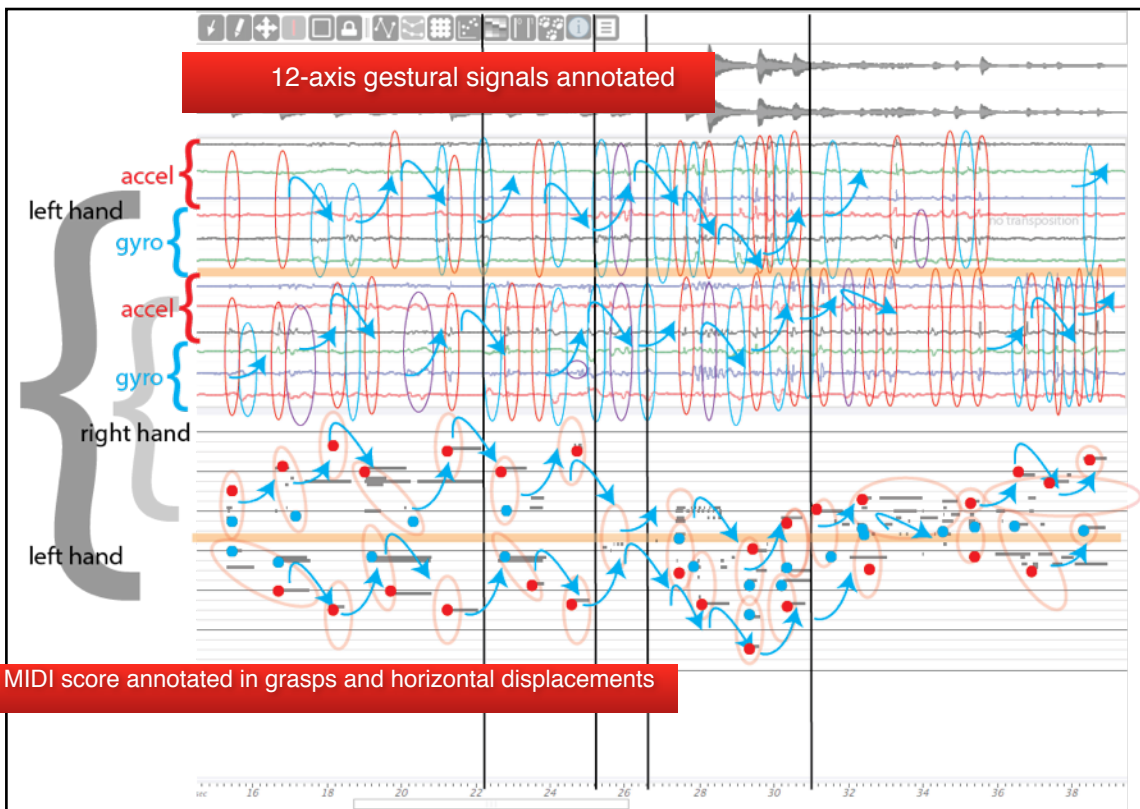
### 3.6 Comparison of reduced pitch representation to the original score

A comparison of the latter reduced proportional representation (fig. 8c) of the grasp layer of the original score to the original (fig. 2) yields the following observations, as presented in fig. 9:

- Information concerning rhythm, articulation, dynamics, pedaling and expression has been removed. Our attempt is to relieve the fusion of those parameters in notation, searching to represent Ferneyhough's proposed "gestural patterning" in the first phase of the learning process only in terms of horizontal displacement of hands over the keyboard and pitch reduction to the boundaries of this gesture. We present pitch information which is definitive for the horizontal displacement of the hands. We have showed that this information constitutes implicit knowledge for the performer, but it may also be inferred from the gestural signals alone.
- Pitch information is re-arranged as follows: It is renated in four staves instead of the original two. This representation of pitch-space in a continuum, i.e higher and lower pitch visible as such in the notation, differs from the original, where clef changes, ledger lines and additional octave displacement brackets often conceal the distribution of pitch in the notational space.
- It is reduced in only the amount of pitch which is necessary for the representation of the hand displacement. This amounts to 20% of the original pitch content in this particular instance.
- Blue arrows indicate change of position in full accordance to the gestural signal.
- Higher-order segmentation and parsing of the output score clarifies patterns which are not readily visible in the original score.
- Ontologically, the output score is generated from a MIDI stream during performance and offers augmented multimodal feedback to the performer during learning and performance. It reflects on performance at different temporal scales, in the sense of its past, present and future manifestations. The latter correspond to: prior knowledge and prioritisations (as the

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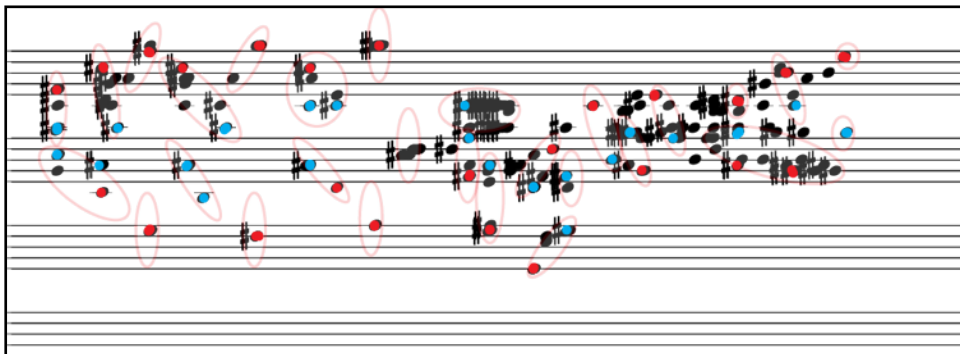
<sup>1</sup> An open source rendering engine dedicated to symbolic music notation, see at <http://guidolib.sf.net>



**Figure 6.** Comparison of two annotations: the annotation of the original score in grasps transposed on the MIDI score and the annotation of the gestural signal in attacks and displacements. Watch the matching blue arrowed patterns.

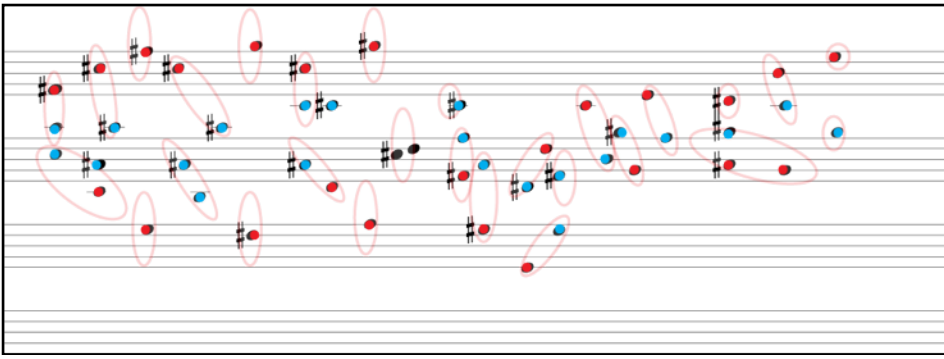


**Figure 7.** Automatic transcription of the MIDI piano-roll: Reduced proportional representation of pitch in four staves.

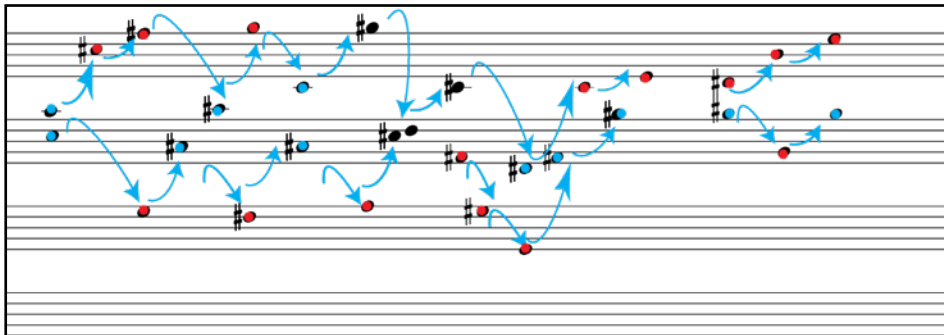


**Figure 8a.** Annotation of fig. 7 in grasps

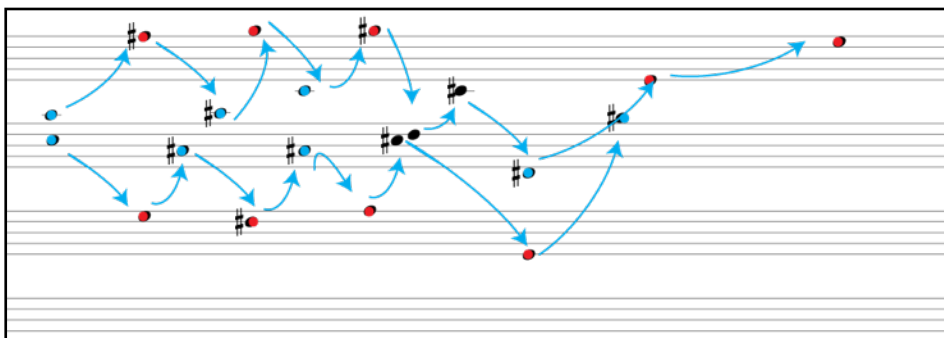




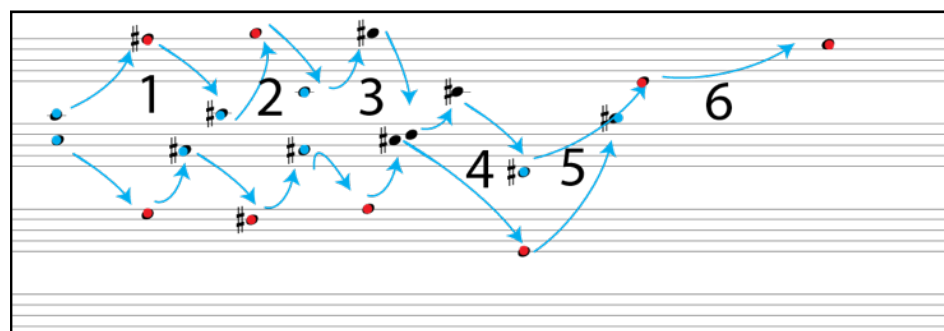
**Figure 8b.** Annotation of fig. 7 keeping only grasp boundaries



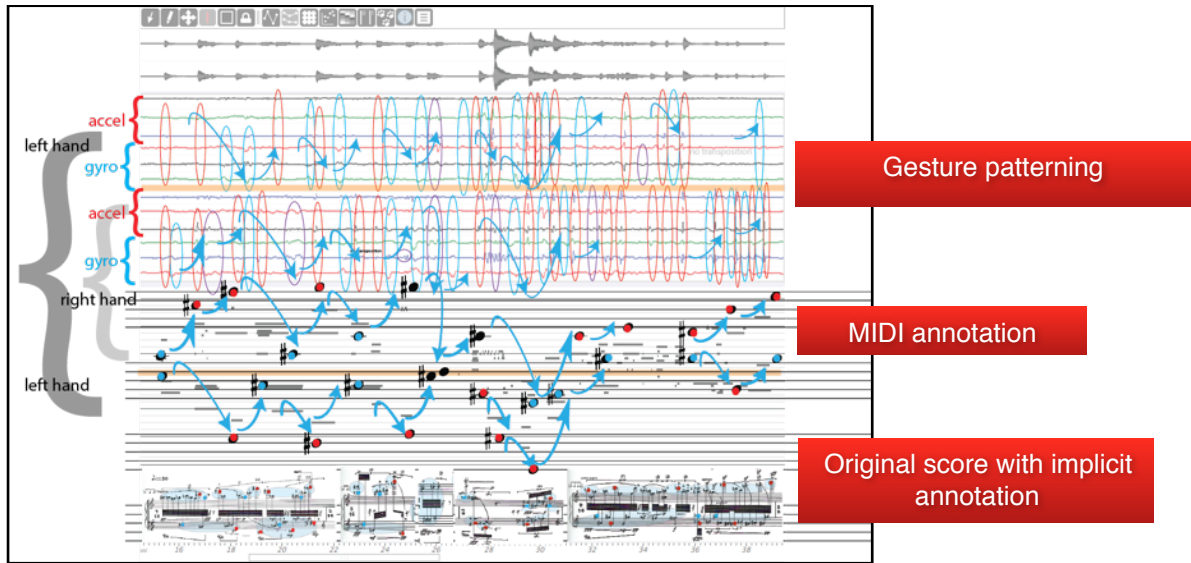
**Figure 8c.** Annotation of fig. 7 keeping one grasp boundary and indicating the gestural pattern



**Figure 8d.** Arm layer: Annotation of fig. 7 keeping one the maxima and minima of arm trajectories, without intermediate position changes



**Figure 8e.** Segmentation and parsing: The relationship of the arm movement is heterodirectional (opposite motion) in the first 3 symmetrical units and homodirectional (parallel motion) in the units 4 to 6.



**Figure 9.** From top to bottom: The alignment of gesture patterning, MIDI patterning with pitch reduction and the original score annotation.

implicit annotation); observed realisation (gestural patterning); anticipated further notational transformations (when the output score enters in the learning cycle and is itself being processed and refined during the second and third stages of learning).

- From an embodied cognition point of view, output notations are embodied and extended: They are produced through performative actions, they represent multimodal data, they can be interactively controlled through gesture and they can dynamically generate new varied performances. They can be considered as the visualisation and medial extension of the player's embodied navigation<sup>2</sup> in the score-space, creating an interactive feedback loop between learning and performance.

#### 4. CURRENT APPLICATIONS

We currently use the output gesturally annotated score in synchronisation with videos and integrated in INScore [15] dynamic representations, to be presented in TENOR 2016. Following previous work on the GestCom (*gesture cutting through textual complexity*) [16], a system combining the INScore and the *motionfollower* architecture, we plan to integrate and dynamically interact with the output representation of fig. 9 in real-time. For a review of GestCom, please look at the video linked in [17].

#### 5. FUTURE PERSPECTIVES

Future projections of this work include:

- The comparison of differently prioritised performances corresponding to the second and third phase of learning as defined by Ferneyhough.
- The probabilistic inference of the annotated MIDI score as a hidden layer emitting the gestural signal in a hierarchical Hidden Markov Model.
- Applications in learning and performance documentation, interaction design, score-following and pedagogy.

#### 6. CONCLUSION

We have presented a methodology for the processing of complex piano notation by means of multimodal performance data. Our case study is *Lemma-Icon-Epigram* for solo piano by Brian Ferneyhough. Ferneyhough's notion of global gestural patterning manifests as subjective score annotation observable in objective performance data. We have employed this patterning in output embodied representations, which sample the original symbolic notation after the observed gestural patterning. This work is promising for the probabilistic inference of the patterning and the notation from multimodal data. Applications range from performance documentation and pedagogy to interactive systems design and score-following.

#### Acknowledgments

This work used recordings conducted in the context of the IRCAM Musical Research Residency 2014. It wouldn't have been possible without the doctoral funding of the LabEx GREAM, Université de Strasbourg and the IRCAM. Special acknowledgments to Dominique Fober for specially developing the command lines for the

<sup>2</sup>For a review of the concept of the embodied navigation of complex notation and its foundation on the field of embodied and extended cognition, please review [18].

automatic transcription of the MIDI piano-roll into reduced proportional representations.

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