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# Developing Software for Digital Musicology: Inside an Experimental Laboratory

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## ABSTRACT

*This article presents the concept of the experimental musicology laboratory through the development of several technologies (iAnalysis, EAnalysis, MotusLabTool). The aim is to consider musicological research as the result of an experimental empirical approach which combines methods (musicological methods and digital algorithms), tools (theoretical tools, technologies and software) and sources (traces or phonographic works) all in the same process. As an illustration of this musicological approach, we present three types of highly efficient visualization examples based on the superposition of several transparent colored representations and on the combination of several representations to facilitate the musicological interpretation of the data.*

## 1. INTRODUCTION

The term “digital musicology” encompasses a wide range of scholarly practices, from the use of software to navigate and listen to digital audio files – which we refer to here as “weak digital musicology” – to the development of software or technologies for historical study or musical analysis – which we will call “strong digital musicology”. In general, the practice of digital musicology reflects a desire to go beyond the traditional methods of musicology and towards a multidisciplinary or even interdisciplinary approach. One of the main goals is to find methods in other fields that overcome the dead ends confronting the musicologist. These impasses can have many origins: the study of a complex repertoire for its spectral richness, the analysis of structures that are dense and difficult to analyze (for example, long musical forms presenting heterarchical or rhizomic aspects), the study of creative processes involving a team of several people producing many files in different formats, the analysis of works based on algorithmic

processes requiring an understanding of the computer developments made by the artists or the computer music assistants, the study of interpretation or improvisation processes on digital or hybrid musical instruments, and so on. These musicological practices are “outside-the-box” and often require the adaptation of methods from other fields (such as mathematics, computer science, or musical acoustics), or even the creation of new methods.

The practice of strong digital musicology remains a real challenge for the researcher. It requires going beyond one's musicological specialization and training in many other disciplines. It also often requires acquiring software development skills, a practice that is rarely covered by university musicology curricula. It is also challenging because strong digital musicology confronts the musicologist with difficulties unknown in other fields. The lack of musicological exchange formats between software programs is a striking example; how to work on the analysis of a certain musical form with various programs. In this practice of digital musicology, the researcher will usually be a composer who uses or develops research-creation methods for composing his works and developing related technologies.

A weak digital musicology has, however, been developing for about twenty years with the improvement of the multimedia capabilities of personal computers. The methods used in this new discipline of musicology are quite well known: support for the visualization of the audio signal, the use of semi-automatic techniques for the analysis of interpretation (for example, by comparing tempi and intensities), the annotation of scores, the study of digitized texts, the creation of databases for the classification of references, definitions, musical instruments, images, scores, etc. In these areas, there are many software programs that are widely used by musicologists [4].

The transition from a weak digital musicology to a strong digital musicology is not a simple change of scale but requires the acceptance of a real epistemological break by integrating digital methods into the more traditional methods of musicology. Nicholas Cook was one of the first to defend the need for an evolution towards digital musicology through the use of MIR technologies<sup>1</sup> [2]. One of the most profound breaks lies in the understanding of the relationship between technologies (software or hardware), data, and methods. Considering software use as a musicological research method is not obvious at first glance. In

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<sup>1</sup> Music Information Retrieval (MIR) technologies are based on the extraction and analysis of information from digital sources (audio, text, image or data).

practice however, not only does technology provide methods that contribute to our knowledge of the data, but also to the workflow used in musicology. Bruno Latour, following Gilbert Simondon, has highlighted the way in which technologies construct our knowledge through specific scientific methods [16, 21]. In musicology, these methods are usually based on one or more theories that allow the study of a musical object. In digital musicology, technologies are combined with methods – practical, theoretical, and digital – and data – musical (e.g., score) and digital – to allow us to study the musical object in question. Technologies, methods, and data cannot be considered independently. This epistemological rupture can pose a problem by highlighting the strong dependence of methods on the digital domain itself. But this dependence also multiplies possibilities and offers new opportunities for the analysis of repertoires that have been little studied.

The aim of this article is to show how we have progressively integrated strong methods of digital musicology in the development of software, a true laboratory of experimentation in musical analysis.

## 2. TECHNOLOGIES

### 2.1. iAnalyse, EAnalysis, and MotusLabTools

The development of iAnalyse started in 2005 and the first public version was available in 2007 [6]. iAnalyse was intended to be the equivalent of a slide show software, but with features to synchronize graphical elements (slide, image, drawing, text, etc.) with an audio-visual file. iAnalyse 1 allowed the creation of listening guides with demonstrations of music analysis. The software was particularly well suited to instrumental music through the creation of annotated and animated scores. In 2011, Leigh Landy and Simon Emmerson from De Monfort University in Leicester asked us to create a version adapted to electroacoustic music and, more generally to non-notated music. We developed EAnalysis as part of the New Multimedia Tools for Electroacoustic Music Analysis project<sup>2</sup> [3, 11, 12]. The development of EAnalysis allowed us to move on from a type of software for interactive music presentation to one for music analysis support. We modularized the architecture to facilitate experimentation and the development of new analysis and presentation methods. In 2019, we integrated EAnalysis 2 into iAnalyse 5<sup>3</sup>. This latest version pursues the ideas of modularity and experimentation implemented using EAnalysis. Version 6 of iAnalysis, currently under development, is fully designed as a modular laboratory in which we experiment with new forms of data visualization and analysis.

Parallel to these two projects, in 2015 we started collaborating with the music company Motus<sup>4</sup> on the study of spatialized interpretation of acousmatic music [10]. In this context, we developed the first version of a program for synchronized MIDI, audio and video recordings of musical

performances on loudspeaker orchestras (acousmoniums). The MotusLabTool<sup>5</sup> software has been used to record nearly 500 performances and is now being used with several acousmoniums in France, Belgium and Japan.

The next version of iAnalyse will integrate the recording and visualization functions of MotusLabTool.

### 2.2. Languages and Environments

Versions of this software have been developed for multiple languages and environments:

- The first versions of iAnalysis were developed using the REALbasic environment (now called Xojo).
- Versions 1 to 4 of iAnalyse and EAnalysis were developed in Objective-C using the Xcode environment.
- The MotusLabTool model (version 1) was developed in the Max environment.
- iAnalyse version 5 and MotusLabTool version 2 were developed in Swift using the Xcode environment.

Since we work mainly with MacOS, it seemed easier to develop these programs for this platform. This choice may be criticized (no version for Windows or Linux), but it has turned out to be the right one (especially since Swift language has come into use) as it enabled us to use a very rapid development flow to concretize our ideas and to use complex functions (for example the functions related to the Accelerate framework for the FFT calculation). Swift is often considered a modern language because it combines the simplicity of high-level scripting languages with the power of low-level languages, while integrating several types of programming (object-oriented, functional, protocol-oriented).

During the New Multimedia Tools for Electroacoustic Music Analysis project, we analyzed the development of many of the software tools used to support music analysis [4], and one of the main obstacles to development was the use of external libraries. A typical example is the Acousmograph<sup>6</sup>, whose development is based on many libraries that are now obsolete, maintenance has become very difficult, and the software does not run on more recent systems. With iAnalyse, we have therefore gradually converted the functions realized in external libraries (such as SoX<sup>7</sup>) to native ones.

### 2.3. The iAnalyse Architecture

The architecture of iAnalysis has gradually moved towards a separation between the audiovisual player and the representations. Use in the context of music analysis requires the generation of representations from modified sources (file with audio channels mixed in monophony, multitrack file mixed in stereophony, filtered audio file, etc.). However, these sources are not optimal for audio playback during analysis. Playback must be performed from a reference

<sup>2</sup> <https://www.dmu.ac.uk/research/research-faculties-and-institutes/technology/mtirc/projects.aspx>.

<sup>3</sup> <http://ianalyse5.pierrecouprie.fr>.

<sup>4</sup> <https://motus.fr>.

<sup>5</sup> <https://github.com/pierrecouprie/MotusLabTool>.

<sup>6</sup> <https://inagr.com/fr/showcase/news/203>.

<sup>7</sup> <https://sox.sourceforge.net>.

file that has been adapted for stereo listening. The architecture of iAnalysis is therefore organized in four separate parts:

1. Import of files in various formats. Some of them are converted to facilitate subsequent operations, such as data files, MIDI, MusicXML. A copy of the original file is also kept in the project.
2. The audiovisual player, which provides time synchronization between all the representations.
3. Computational tools to create or transform data and calculate representations.
4. The visualization interface of representations, temporal scrolling of which is synchronized with the audiovisual player.

### 3. A LABORATORY FOR DIGITAL MUSICOLOGY

#### 3.1. Toward a Context-based Musicology

As well as the technological aspect, there are also questions and difficulties that are solely musicological [3, 7, 9]. As we have already shown, digital musicology is part of an epistemological rupture that has rarely been integrated in university instruction. The researcher thus faces several difficulties:

- Difficulty in learning the methods of computer science, mathematics, and musical acoustics. The online courses or books are designed for scientists in the exact sciences and not in the humanities, there is a lack of information that is part of the foundation of these scientific disciplines, but is often unknown to musicologists. For this reason, researchers are generally limited to using software that has already been developed, and the practice of digital musicology generally means simply using such software.
- Difficulty in using scripts or open-source code already developed in exact science projects that could be very useful in musicology. The compilation, maintenance, and use of such codes require a high level of computer literacy and are generally inaccessible to a musicologist.
- The lack of an exchange format for musical data also complicates the work of the musicologist. For example, the MEI<sup>8</sup> format often used in digital musicology is generally unsuitable for musical analysis.
- Difficulty in transferring methods between different scientific fields. Researchers do not generally speak the same language: for example, the distinction between a "singing voice" and a "speaking voice" is not the same in contemporary music, ethnomusicology, or musical acoustics.
- Difficulty using visualization or graphs formatted for other fields, such as musical acoustics or computer science that are not adapted to musicology.

Researchers in the exact sciences judge the "scientific quality" of a graph by the precision of the values displayed and the scales used on the axes and in the key. For example, for the musicologist, the precision in dB of an intensity curve is of limited importance, whereas the ability to easily compare amplitude evolution between two channels is essential when analyzing the spectromorphologies created by musicians. In this case, the usual waveform visualization is not sufficiently informative for a musicologist. It is preferable to superimpose the visualization of the channels (Figure 1).

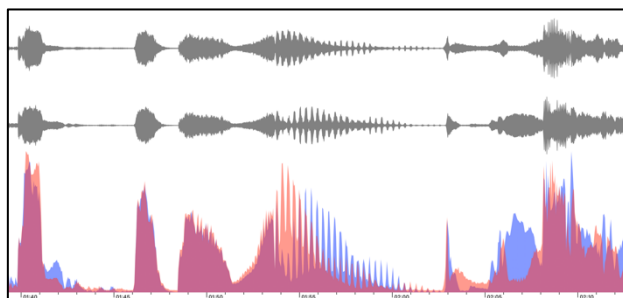


Figure 1: Two examples of amplitude visualization performed on an excerpt of *Ah Dulcinea* by Alain Savouret: (top) the waveform, (bottom) the RMS amplitude on two layers.

While some fields, such as the study of contemporary creation, have fully transitioned to the practice of digital musicology through the use of programming environments, this is still not the case for a large portion of musicologists, even though many of them work with digital sources. This shift requires a rethinking of methods of study and musical analysis in order to integrate digital methods. This is a practice I call "context-based musicology" because it requires

1. Taking into account the profound change in musical listening practices since the advent of digital technology [22]. This change can still barely be perceived in musicology, whereas it has been fully integrated into musical creation, for example with the development of concatenative synthesis techniques that extend fragmented listening.
2. Reconciling data, software and methods in musicological theory in order to take into account the way these technologies construct our knowledge [16].
3. Thinking of sources no longer as mere documents, but as data and media that are both human and digital constructions. This implies distinguishing between the "trace", the "document" and the "work", or speaking of these elements as "composite cultural beings" [15], i.e. objects that mix different types of realities.

With the consideration of these questions, we are moving from a "general musicology" [17] which is designed to encompass methods coming from various scientific domains (history, music theory, sociology, aesthetics, philosophy, etc.) to a "context-based musicology" centered on digital objects, including sources, software and methods.

<sup>8</sup> The Music Encoding Initiative (MEI) format is a more open version of the MusicXML format for encoding sheet music in XML.

### 3.2. A Digital Musicology Laboratory

Considering musicology in a digital regime requires profound changes in methods: the source no longer has a single reality, the document is no longer available on a single medium, the visualization of the document results from a translation process that can produce multiple representations, the software and tools build knowledge about the objects as much as the musicologist does, and the latter must take this knowledge into account through feedback, etc. For this reason, we first developed a framework [5] for our musicological research into the repertoire of music using technology, such as electroacoustic or computer music. At the heart of this framework were also methods of musical analysis based on various theories, as well as methods of representation produced in digital audio and musical acoustics. This first step helped us to structure the development of our software. Over the last few months, this framework has been gradually transformed to integrate the software itself. It became clear that we needed to bring together the sources, methods and tools of both musicology and digital musicology in a single entity: a digital musicology laboratory.

## 4. EXPERIMENTATION

In order to demonstrate how the experiments are carried out in this “laboratory” software, we present two types of representation developed with iAnalysis, which are not generally used in the fields of musical acoustics or computer science, while they have proven to be very useful in musicology.

### 4.1. Colored Layers of Spectrograms and Chromograms

The first group of representations consists of an overlay of colored, similar visualizations to facilitate the actual comparative musical analysis.

In 2019, we worked on a research project about the sheng instrument in contemporary musical creation<sup>9</sup>. We held a free improvisation session at Ircam with the musician Li Lin Chin on the sheng and Benjamin Levy on the automatic improvisation software OMax<sup>10</sup>. Our goal was to develop representations that show the behavior of the OMax software and its interactions with the sheng musician. The audio was recorded in multitrack<sup>11</sup>. Two visualizations were added to iAnalysis: the multilayered sonogram (Figure 2) and the multilayered chromogram (Figure 3).

The first figure (figure 2) simply consists of a superposition of transparent logarithmic sonograms. Each sonogram is tinted with a color enabling comparison of the musician's playing (in red) and the three iterations of OMax (in orange, green and blue). The processes used by the improvisation software are thus immediately

recognizable: transposition, recording-playback with a time-lag, densification by duplication and their combinations.

The second figure (figure 3) uses the same principle of superposition from a chromogram<sup>12</sup>. In this case, as the sheng is principally a harmonic instrument<sup>13</sup>, this type of representation proves to be most suitable for the recording. In order to improve readability, we decided to draw the dynamic profile (amplitude RMS) directly on the pitches, which permits correlation of data between the different tracks (red, green, blue and orange). Here also, the interaction between the sheng (in red) and the software (the other colors) is clearly visible whereas the spectral texture is a somewhat complex: response of the musician on some morphologies, morphological differentiation of pitches, improvisation strategies between the musician and each iteration of the software, software fragmentation of sounds, etc.

### 4.2. Self-Similarity Matrix (SSM)

SSM are particularly relevant in the analysis of musical form or microstructure [8, 13, 18, 19]. As macroscopies<sup>14</sup>, they also facilitate the exploration or navigation of long audio files. Bruno Bachimont speaks of “laboratory objects” [1] to describe artistic objects that require an approach that is both precise and global to account for their complexity on multiple levels. SSM are perfectly suited to the study of this type of object. However, interpretation is difficult for the musicologist, which is why we have developed an interpretation-assistance system. This consists of 3 representations (figure 3):

1. (Top) A SSM computed from the FFT or multiple audio descriptors and a curve representing the novelty parameter.
2. Segmentation is extracted from the novelty parameter (yellow and blue graphs) using the Foote and Cooper technique based on peak detection [14].
3. A playback head (green) can be moved to display the result of a distance computation just below it (warm colors represent small distances). Finally, a main playback head (red) is used to navigate through the audio playback.

The musical work represented in this figure is *Burning bright* by Hugues Dufourt. This is a 64-minute piece for percussion composed in a single movement. Figure 3 also presents the segmentation (at the bottom) into tracks proposed in the recording. The aim is to facilitate the analysis of the musical form, which is difficult to grasp over such a long duration, but also to study concordances with the segmentation selected for the disc edition by the musicians and composer.

This interface is only in an experimental phase, but makes it possible to consider improvements for the analysis of long works or collections of works.

<sup>9</sup> The project is led by composer and musicologist Lin-Ni Liao (<http://www.tpmc-paris.com/sheng-research-2019-2020/>).

<sup>10</sup> OMax is an automatic improvisation software developed at Ircam, it has given rise to many variations such as SoMax or, more recently, DyCI2 (see : <https://www.ircam.fr/projects/pages/omax/>).

<sup>11</sup> One stereo track for the sheng and 3 stereo tracks for the 3 iterations of OMax spatialized around the musician.

<sup>12</sup> The chromogram represents the intensity of each note calculated from the FFT and plotted over a single octave.

<sup>13</sup> Some blowing effects and key noises were also used by the musician but they are not relevant in this extract.

<sup>14</sup> The term “macroscopy” is used here, in reference to the macroscope [20], to refer to representations that provide a global view of the information extracted from the signal while keeping track of the details.

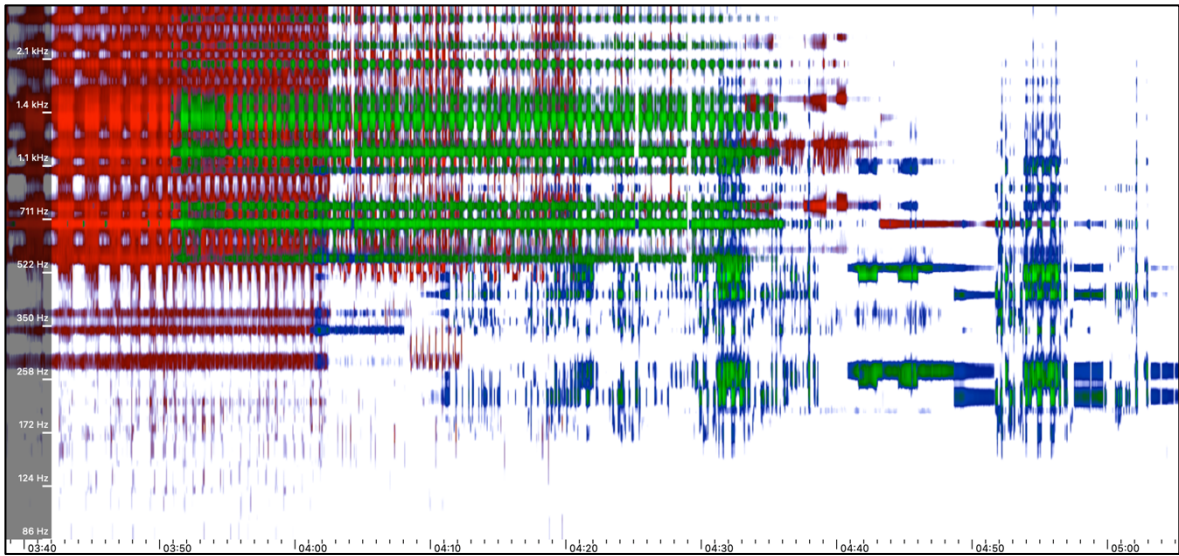


Figure 2. Multilayered sonogram to visualize correlations between recorded audio tracks.

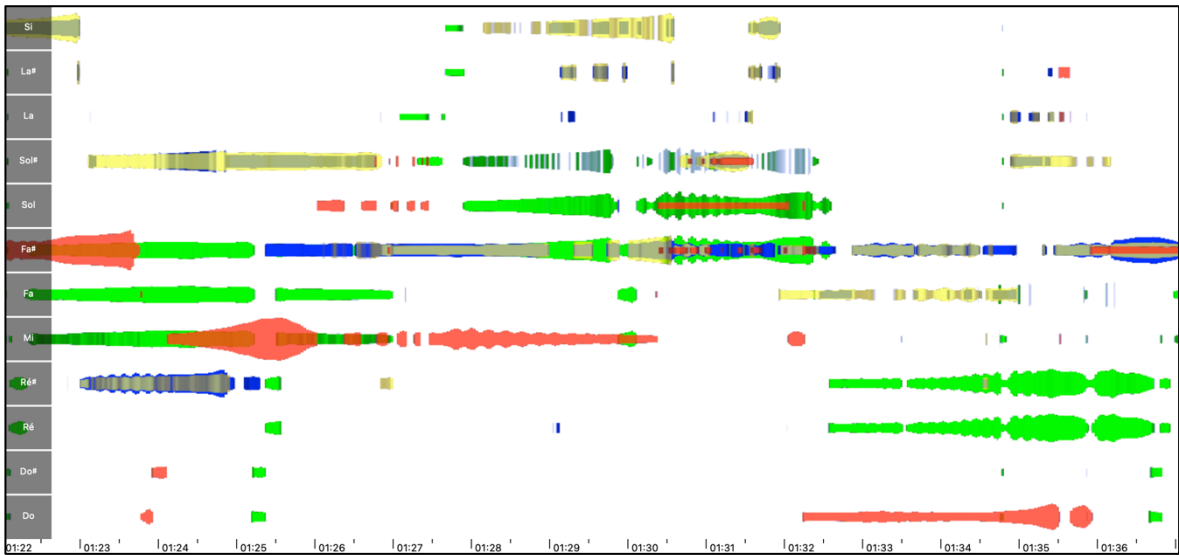


Figure 3. Multilayered chromagram to visualize correlations between recorded audio tracks.

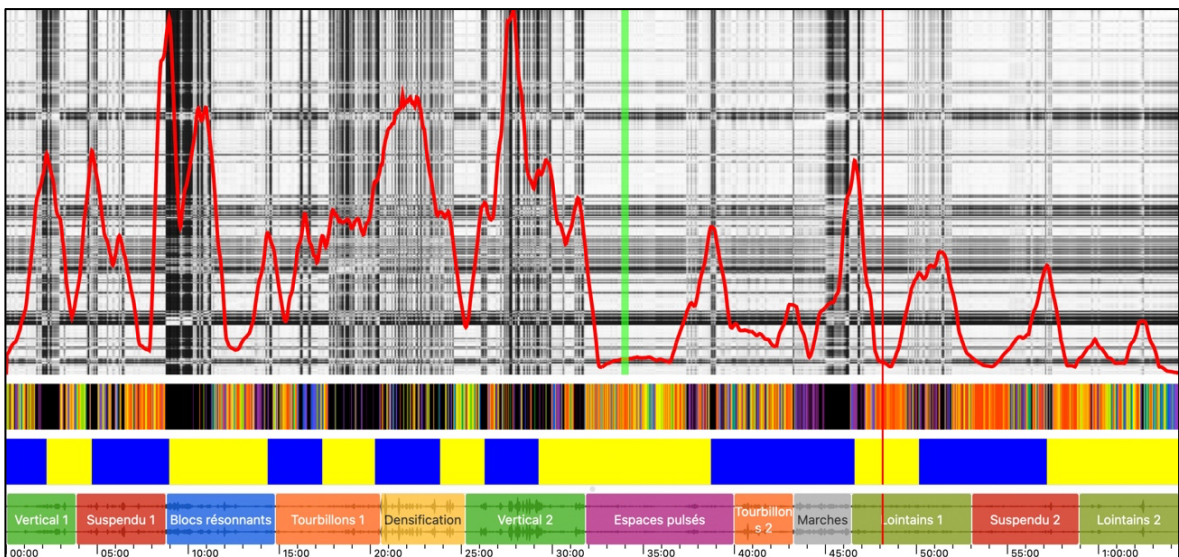


Figure 4. The interface is designed to assist in reading a self-similarity matrix (SSM) for the study of musical form in *Burning bright* by Hugues Dufourt.

### 4.3. Contribution to Digital Musicology

So what are the results of these two examples? First, the visualizations are not really new, but rather the result of an adaptation of already existing representations (spectrogram, chromogram, SSM). However, their use here is very different: the superposition of colored and transparent representations, the addition of the RMS amplitude in the chromogram and the association of several representations to facilitate the reading of a SSM. This approach is based on the use of the experimental laboratory in a contextual musicological approach. This transfer of methods makes it possible to create tools adapted to musicological research.

Figure 3 shows an example of representations in the process of experimentation. The interface is still far from being fully adapted. We borrow techniques from the similarity search. Although the acceptance of error (cost) is common in exact sciences, it is not common in musicology. Also, the development of an analysis method that does not produce a 100% reliable result is generally not considered valid. In this figure, the automatic segmentation obtained from the novelty parameter is still largely imperfect, but its association with a color gradient showing the probable similarities can become a valuable tool for musicology.

## 5. CONCLUSION

In this article we have presented technologies that we have been developing for several years for our musicological research on the repertoire of electroacoustic music. From software allowing the creation of listening guides with a musical mediation goal, we have progressively moved towards the development of an experimental laboratory for digital musicology. This concept of a digital laboratory is related to that of contextual musicology. Instead of using digital technology as a tool for musicology, it is a matter of considering methods (musicological methods and digital algorithms), tools (theoretical tools, technologies and software) with sources (traces or phonographic works). This synergy is strongly contextualized and the methods differ according to the repertoire studied. Moreover, contextual musicology is more respectful of the often hybrid sources used in the study of experimental repertoires. It is therefore also a question of taking their specificities into account, in particular, those of digital sources.

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