An Innovative Method for the Study of African Musical Scales: Cognitive and Technical Aspects

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Abstract — **Our aim is to demonstrate how music computing can increase efficiency in a field of humanities such as ethnomusicology. In particular, we will discuss issues concerning musical scales in Central Africa. We will describe a recent methodology developed by a multidisciplinary team composed of researchers from IRCAM and the CNRS. This methodology allows us to understand the implicit behaviour of musicians and the cognitive cultural categories of the functioning of scale systems.**

Keywords: ethnomusicology, music computing, field, experimental procedure, analysis and synthesis of the singing voice and instrumental sound.

I. Introduction

Musical scales are a most interesting subject for the study of cognitive processes related to musical *conception* and musical *perception* because they are the basis for *all melodic construction and because all melodies are concrete manifestations of a musical scale*.

In the oral tradition cultures of Central Africa, the rules that underlie musical systems are rarely verbalized, and studying them requires the use of appropriate investigation methods. The study of scales is no exception and only methods involving *experimentation* can allow us to uncover the principles on which they are based. Our approach was based on earlier work carried out in the Central African Republic and in Indonesia under the direction of Simha Arom[1] (Arom & Voisin 1998; Arom, Voisin & Léothaud 1997), which demonstrated the necessity of developing methods to avoid the pitfall of verbalization: "There are no verbalized comments regarding abstract concepts such as *scale*, *degree* and *interval*, and in fact there is practically *no way to verbalize them*. There is indeed *conception*, but no *conceptualization*" (Arom 1991: 22). Such methods require that we go beyond verbal questioning in favor of another mode of inquiry that harnesses the know-how of the musicians through their active involvement in the experimental process (Fernando 2003).

The team of the Ethnomusicology Department of LACITO-CNRS, which carried out research from 1989 to 1993 with six ethnic groups of the Central African Republic, thus used a synthesizer (Yamaha DX 7-II FD) in conjunction with a computer (Macintosh SE/30) to analyze the reactions of the musicians. The synthesizer, simulating a xylophone with removable strips of wood placed on the keyboard, allowed the musicians to test, *in real playing conditions*, the various *models* of musical scales that they were offered. When the models were rejected – entirely or partly –, a cursor offered the instrumentalists themselves the possibility of modifying each of the degrees of the scales submitted for their evaluation. This system thus allowed them to progressively verify – after each modification – the conformity of the scales thus obtained by playing pieces *from their traditional repertoire* on this simulated xylophone. Simultaneously, previously developed synthetic timbres allowed for better determination of the xylophonists' conception of the timbre of their instrument and evaluation of the effect on the tuning.

By simulating close-to-real playing conditions and allowing the instrumentalists themselves to modify the scales offered, this experimental approach allowed for real interaction between the researchers and xylophonists. When applied to the vocal polyphonies of the Aka Pygmies, the experiment was not as successful for technical reasons: at the time, it was impossible to synthetically reproduce the timbre of the voice of a Pygmy singer in a reliable manner. Also, the simulation of a *polyphonic* singing situation was only *partial*: we could either record a solo singer, adding his voice to a polyphony reproduced by the synthesizer, or a soloist – supported by one or two synthesized parts – to which we would progressively add other "live" singers – with the synthesized parts being gradually removed. In the former case, the analysis could only focus on a single voice; in the latter, the separation of all of the voices of the polyphony and the control of the correspondence of the soloist's scale with the one proposed by the synthesizer was not possible due to the limitations of the available equipment.

Recent advances in digital and sound processing techniques now allow for the development of highly innovative experimental study and analysis tools.

Our goal here is to present the *methods* that were designed to study the musical scales of two oral tradition populations in Cameroon, the Bedzan Pygmies and the Ouldémé.

[1] This team was directed by Simha Arom and included Vincent Dehoux, Susanne Fürniss, Gilles Léothaud and Frédéric Voisin within Research Group 0948 of the CNRS: "L'étude des musiques d'Afrique centrale comme révélateur de savoirs non verbalisés", laboratoire LACITO-CNRS (France).

Our research program[2] included two parts, one for the *vocal polyphonies of the Bedzan Pygmies*, the other for the *vocal-instrumental hocket music of Ouldémé women*. In both cases we wanted to understand how the people perpetuating these traditions conceived of their musical scales. The experimental methods used allowed for complete *interaction* between the researchers, who offered theoretical models, and the musicians, who could *test* them and/or *modify them themselves*, using the systems provided for this purpose.

For the Bedzan Pygmies, this involved 1) analyzing, beyond the pitch fluctuations inherent to the singing voice, the size of the intervals that separate the various degrees of the scale system and 2) modifying these pitches in order to check the researchers' hypotheses with the musicians.

For Ouldémé music, this involved making a series of flute *artifacts* to allow the musicians to control their tuning with extreme accuracy. These flute *artifacts* were made from sensors mounted on bakelite tubes and connected to a physical modeling synthesis program.

As we see, the specificity of our method is that it allows for transformation of polyphony through modification of the pitches of the degrees within it. It seems to us that this is *the only way to confirm researchers' hypotheses regarding the native conception of scale systems with the musicians*.

II. The Vocal Polyphony of the Bedzan Pygmies

The The polyphonic songs of the Bedzan Pygmies of central Cameroon have four parts, all of which have names in the local language, and which correspond to different voice ranges, from low to high: *nkwO bunk4æ*, the "voice of big (men)", *nkwO b2mb2b4a*, the "voice of young men", *nkwO beyi*,, the "voice of (big) women" and *nkwO bwesO*, the "voice of small (children)". As in most types of Central African music, these polyphonies are metric, cyclical and based on the principle of ostinato with variations: the same musical material recurs, with a greater or lesser degree of variation, at regular intervals; it is therefore often possible to deduce the minimal expression from which the different variations are made.

In most cases, the songs are sung *a cappella*, i.e. with no instrumental accompaniment; there is thus no stable reference for the pitches that are sung. Comparison of several versions of the same piece, sung by the same musicians at different times, shows not simply that there is no absolute pitch – from one version to another the same melodic phrase may be sung at very different pitch levels – but also that the *intervals* that separate the various constitutive degrees of the song are not stable. Furthermore, even when the songs are accompanied by a melodic instrument – in this case a harp-zither – the tuning of the instrument, from one playing to another, involves the same degree of fluctuation.

The rules that underlie the musical system of the Bedzan are not verbalized. For native musicians the musical scale does not exist in and of itself, i.e. independently of the repertoire to which it applies. It only exists in its execution, and a study of the scales can only be based on *pieces* drawn from the traditional repertoire.

We therefore sought to develop an experimental system that would take these constraints into account involving:

– Using the original musical material, so that the various experiments *were always significant for the musicians*;

– Finding a way to modify only the pitch parameter of this material, i.e. changing the pitch *without changing the timbre*;

– This required the capacity to handle the constitutive parts of the vocal polyphony both individually and synchronously, both upstream (recording) and downstream (reconstitution of the polyphony after sound processing);

We thus sought a system that would be flexible enough to allow for the quickest possible adaptation by researchers to the results that would progressively be obtained during the field experiments – its use *in situ* representing an additional, logistical constraint.

A. The experimental system

The experimental system that we developed involves a sequence of operations:

1) Recording of a polyphony in real performance conditions, followed by

2) A series of acoustic and musicological analyses, leading to

3) Reproduction of the same polyphony with modification of the pitches – but of no other parameters;

4) This version is then given to the musicians for evaluation.

The circle is completed when the musicians sing one or several parts of the polyphony in *re-recording* to supplement and/or correct modifications made to the original recording.

The experimental system uses a combination of a multitrack digital audio recording system, a program for analysis of the sound spectrum and a computer composition program; a specific application was developed within the latter program for analysis and then transformation of the pitches used in the experiments.

List of equipment used:

- PowerBook G4 Apple computer + CD writer
- "Pro-Tools 24" software + specific sound cards + 882 I/O Digidesign interface + special external hard disk
- "Audiosculpt" software (spectral analysis and resynthesis of sound) and "Open Music" (computer composition) Ircam
- "Presonus" Digimax preamplifier for microphones + LEM dynamic microphones (head-borne)
- Mackie 1202 VLZ-Pro mixing board + Fostex 6301B control speakers and Sennheiser HD25 headphones
- Generator set + surge protector

[2] This work, carried out from 2000 to 2002, received support from the French Ministry of Research, within the framework of a program called "Cognitique – action concertée incitative," as *Conception et perception des échelles musicales dans les cultures de tradition orale. Le cas des Pygmées bedzan et des Ouldémé du Cameroun* (project n° A 108).

B. *Description of the experimental method*

The method is applied in several phases: collection of the musical material, its analysis, and modification of the pitches. Each phase thus corresponds to a particular processing of the musical material, the quality of which conditions the next phase. For this reason, we sought to progressively improve the quality of this processing by constantly refining the technical parameters.

1) Multi-track recording

The first phase involves gathering the musical material, the basis of the experimental material. Even in this first phase, certain choices must be made based on our prior knowledge of the music involved. We determined a representative sample of songs to which we would apply our research and the repertoires that would be covered. The musical heritage of the Bedzan is based on a non-closed body of songs, which are divided into several repertoires; each repertoire includes one to three "main songs" and a variable number of "secondary songs". These songs are linked to one or several socio-cultural circumstances, which partly determine who will perform them: the *NbEWE* repertoire, associated with fertility rites, is sung by and for women, while the propitiatory song for the buffalo hunt is performed by men.

We chose two repertoires that are traditionally sung by mixed groups: *n4a* – performed at all major ritual ceremonies and celebrations – and *mgba*, a repertoire for entertainment that accompanies the appearance of secular masks. For each of these repertoires, we systematically examined all of the main songs and one or two of the secondary songs.

In order to obtain musical material that would be usable, we had to record each voice individually, *without isolating the others*. It was thus impossible to make standard recordings that would have involved the entire community. We therefore decided to make multi-track recordings with four singers, each one singing one of the four parts of the polyphony. These recordings were all made in the presence of most of the members of the encampment – and under their supervision; there were many takes and many recordings had to be redone before obtaining performances of a quality that satisfied both the singers and their local audience. The performers had been selected by the Bedzan, who chose the people they considered to be the best singers among them. In each of the two encampments[3] where we carried out our experiments, a rotation naturally developed among a dozen singers; this assured us that we were working with a sample of men and women representative of the entire community. After some time for getting used to the situation, we asked the singers to set aside to the extent possible the variations that they usually sing; these are mostly ornaments, which, because they are very brief, make modification of the corresponding pitches very difficult. The removal of the ornaments greatly simplified the comparison of different versions of the same song[4].

2) Spectral analysis

Before doing the spectral analysis, we first had to systematically select, for each song analyzed, *one* excerpt, in order to avoid overloading the computer equipment and – given the realities of work in the field– to limit the time needed for the data processing that we wanted to do on site. As the music of the Bedzan is cyclic, we chose excerpts of 20 to 30 seconds, corresponding, depending on the case, to about five to ten musical cycles. This duration was sufficient so that the sequence, when made into a loop, was varied enough to avoid its seeming stereotyped and gave the impression that the song was performed in a normal manner. In order to obtain optimum stability of the voices, the selected sequence is never taken less than one minute from the beginning of a recording.

The spectral analysis was done using a program called *AudioSculpt*[5]. It is based on the Fourier transform that yields, in the form of a sonogram, a visualization of the frequency contents of a sound as a function of time. It allows for extraction of the data needed for sound analysis and transformation.

With the spectral analysis of each voice, we use a function of the software that automatically identifies all of the partials that make up the sound analyzed. We select a certain number of parameters that will have a direct effect on the future processing of the sound material. Three parameters were chosen:

1) The minimum length of the partial;

2) The maximum time difference between two sounds of the same frequency. It is this difference that determines whether or not they are considered as belonging to the same partial;

3) The maximum frequency difference between two consecutive points of the analysis, which determines whether these two points are for one single partial or two distinct partials.

The values chosen for these parameters were constantly refined, because they condition not just the quality of the analysis but also that of the re-synthesized sound, i.e. the restitution of the sound after modification of its pitch. In general, we opted for values that allow for detection of changes in pitch; we limited the field of dispersion of each partial however in order to avoid considering two distinct notes as a single note due to vocal gestures (*glissandi* in particular) which could link them. We also had to be careful to not too strictly limit this field of dispersion, in order to take into account the vibrato of the singers, which is often quite pronounced.

From this systematic search for partials – shown graphically on the sonogram in the form of points connected by a line –, we kept only the partials of the fundamental frequency. The Bedzan songs have no – or very few – words, other than those of the *incipit* sung by a soloist; the polyphony is sung with vowels, [o] or [e] in most cases, with no notable difference in intensity. For this reason, the sound spectrum is harmonic and homoge-

[3] The entire Bedzan community represents about 400 members, divided into 6 encampments. We worked in the two main encampments, located about 70 km from each other, each with 60 to 80 people. While many members of these two encampments are related, they nevertheless represent distinct lineages. The Bedzan travel frequently and they all come together for major ceremonies such as the festivities that follow funeral rites.

[4] For each song selected several recordings were made, on different days and with different musicians, in each of the two encampments.

[5] *AudioSculpt* and *OpenMusic* are computer programs designed and developed by Ircam (Paris, France). For further information, consult the site <http://forumnet.ircam.fr>.

neous over all of the degrees sung, which allows us to use the measurements of the fundamental frequencies as references for the analysis of the pitches.

The data for the partials of the fundamental frequency are then gathered in the form of a text file, which includes the total number of partials of the sound file analyzed, the number of measurement points for each partial and, for each of these points, its time (in ms), its frequency (in Hz) and its amplitude (in dB).

In order to accurately analyze the change in pitches in the song, this text file is then exported to a computer musical composition program, *OpenMusic*.

3) The musical analysis

In order to study the melodic and rhythmic structure, "conventional" musical transcriptions were done for the pieces chosen for the experiments. This operation is an essential step for comparison of various versions of the same song and, as a corollary, various actualizations of a given scale. Given the variations of the absolute pitch and the differences that can involve, from one version to another, the number of degrees sung, it was essential to know the intrinsic characteristics of the piece examined to avoid any erroneous interpretation of the results.

Analysis of musical scales involves:

– determination of the number of constitutive degrees present in each sung version,

– observation of their change over time from one cycle to another and, within one cycle, from one position to another,

– evaluation of the size of the intervals that separate the various degrees in order to determine their number and nature.

This analysis is done part by part, but also by a comparison of all of them with respect to each other. It is based on a set of graphic representations specifically developed for this research program within an application developed by Fabrice Marandola called *Scala* in the *OpenMusic* environment (Marandola 2003). In addition to a graphic analysis module, *Scala* includes prior conversion of text files into musical notation and grouping of the separated voices in their polyphonic superposition and then the possibility of modifying the pitches of all – or part of – the analyzed excerpt.

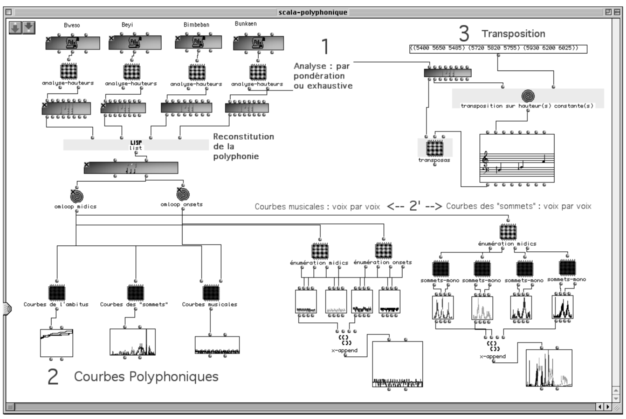


Fig. 1. The Scala application

The first part of the application (part n°1 of figure 1) allows for three main operations:

– the grouping of the analyses of each part, done individually for each of them during the spectral analysis, in a polyphonic superposition faithful to the original excerpt.

– the transformation of time, frequency and amplitude data from the "text files" into musical staff representation, with conversion of frequencies (Hz) into *midicents* (mc), a unit of measurement that combines the Midi norm (60 = C3, 61 = C#3, etc.) with the accuracy of *cents*: 6000 *midicents* indicates C3 while 6020 mc equals C3 + 20 cents.

– the possibility of keeping, for each note sung – and thus for each partial –, the set of all of the points measured, for optimal precision in the monitoring of the changes in pitches and, inversely, to calculate an average for each of the degrees sung. For practical reasons that we will explain below, we chose to keep maximum information for the analytic phase, but to use the averages for the pitch modifications in the later phase of the application.

The second part (part n°2 of figure 1) presents three types of graphic representation, first in polyphonic form, then individually for each of the voices, with the possibility of assembling them in groups of two or three for the purpose of comparison.

The first representation consists of a breakdown of all of the frequencies measured, from low to high, for each of the parts. It gives an indication of the *ambitus* of the voices, the stability of each of the degrees and shows that or those which are common to the various parts.

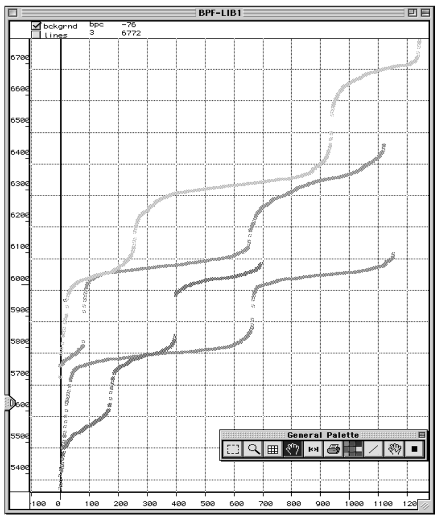


Fig. 2. Ambitus curve

The second graph shows the grouping of the sung pitches as a function of their frequency of appearance; it is in the form of a curve with several *peaks*, which generally correspond to the number of degrees sung. The "slopes" that lead to each peak give an image of what the field of realization of the degree covers.

Some curves have more peaks than constitutive degrees that are really expressed, for two reasons:

1. Depending on the positions of a degree within the melodic phrase (reached via rising or descending, conjunct or disjunct movement), the degree can have quite different realizations;

2. the presence of a wide vibrato between two very stable frequencies can lead to two peaks for the same degree.

The third type of curve allows us to observe the changes in frequencies over time and to compare from one cycle to another – but also within the same cycle –, the dispersion of each of the degrees. This curve constitutes a *melodic* representation of the analyzed excerpt.

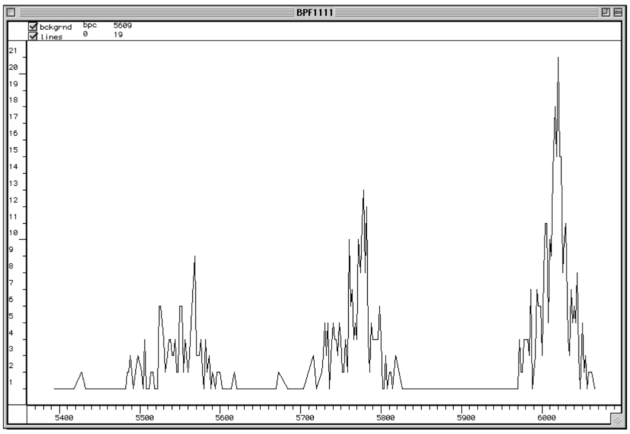


Fig. 3. Ambitus curve

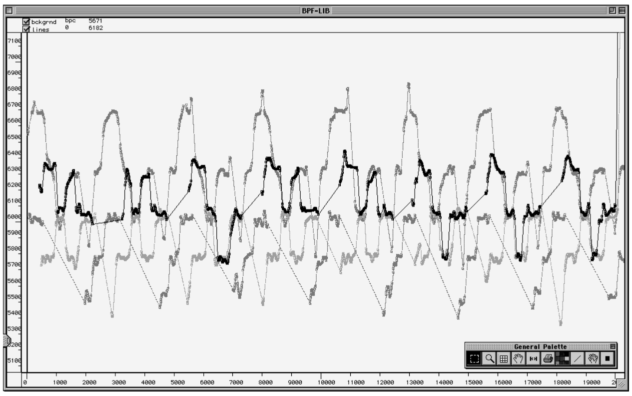


Fig. 4. Polyphonic musical curve (four part)

From these latter two curves, we plot the scale noting, for each of the degrees, the frequency most frequently sung and the margins of its field of dispersion (lower and upper frequencies). This operation is repeated for all of the parts present. This is an estimate based on a statistical analysis of those frequencies that had the greatest number of realizations. From these measurements we then calculate the intervals that separate the various constitutive degrees of the scale. It is clear that when the voices become more stable, this evaluation becomes less ambiguous – because the field of dispersion is then very narrow and the number of identical frequencies is very high: this yields high peaks that are clearly separate from each other. When the voice is unstable on a degree however and several estimations of the most frequently sung frequency are possible, it is essential to use the representation of the melodic curve and the comparison of the peak curves for the various parts. If doubt remains, the musicians should be offered two versions in order to confirm these estimations.

Lastly, as it is statistical analysis that determines the "center of gravity" of each degree sung, there is a risk of an experimental bias being introduced because the long notes, for which more samples are analyzed, have a greater "weight" and thus shift this center of gravity. We can imagine that a long note sung slightly too low or too high could override shorter realizations at another pitch. In fact, long notes are generally the most "accurate", because they allow singers to more easily control and stabilize their voices, but (as mentioned above) we always cross-check the data from the various forms of representation. We have gradually acquired the experience needed to select excerpts that avoid ambiguity as much as possible.

4) Modification and then reconstitution of the polyphony

The third and last part of the computer application (part n°3 of figure 3) modifies all or part of the pitches sung. It acts like a filter – or more precisely a funnel: all of the frequencies between the two limits (lower and upper) of a degree are brought to the determined pitch; for example, all of the frequencies between 6000 and 6100mc are brought to 6050mc. This operation can be done as many times as necessary, for all or part of the sound range. The frequencies that are not within the defined limits remain unchanged. This gives us a new text file, identical to the one from the spectral analysis – except for the frequencies. The "transposition" is done from this modified file, returning to the *Audiosculpt* analysis-synthesis software *via* the execution of a pre-existing procedure in the *OpenMusic* program.

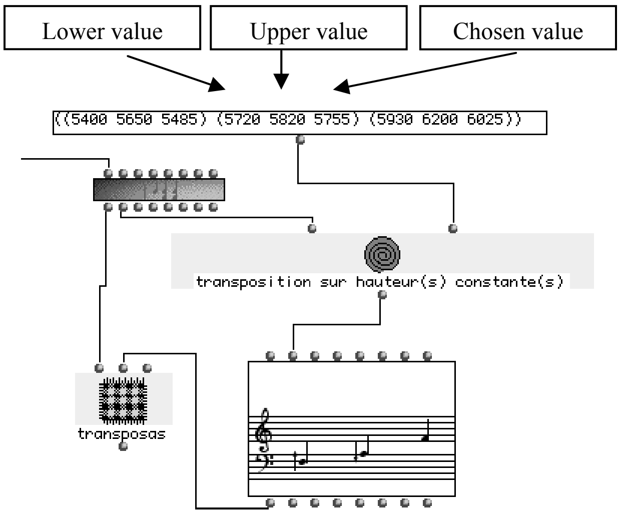
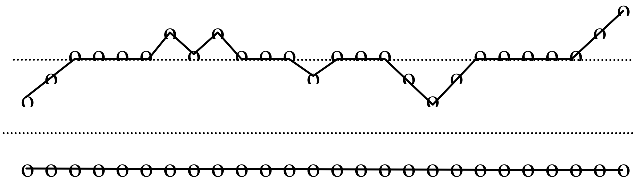


Fig. 5. Modification of pitches in the *Scala* application

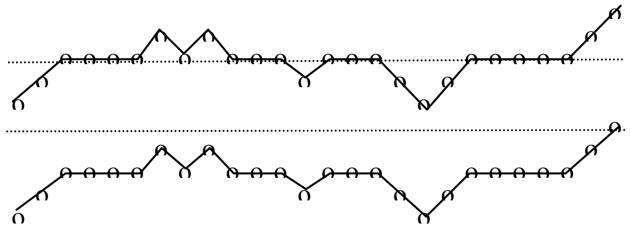
It is at this stage that it becomes necessary to work on a single point, corresponding to the average of the frequencies measured for each degree, rather than on all of the points measured. When all of the points measured – i.e. each sound sample – are brought to a fixed pitch, the micro-variations inherent to singing are eliminated and the sound result is often disappointing, especially because the transitions from one degree to another become abrupt. It is then more effective to work with the second possibility so that the respective "centers of gravity" of each degree correspond to the chosen frequency, without deformation of the vocal gesture. This is a *translation* – upward or downward – of all of the sound samples for a degree so that they coincide with the desired frequency, and not the alignment of all of the samples with the same frequency.

If we want to conserve optimum vocal timbre quality, these translations, which affect the pitch of some degrees of the singing, must remain within relatively strict limits – about a third upward or downward – , which are sufficient for the study we are considering. When the changes in pitch are more pronounced, they sometimes also affect the length of the degree sung, a phenomenon that we correct with the multi-track program Pro-Tools, within which the polyphony is reconstituted.

Alignment of all samples measured for a given note:

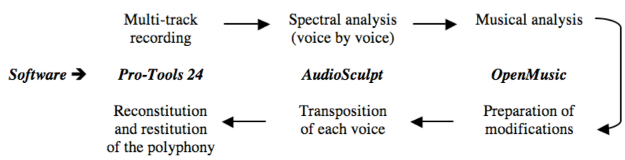


Translation of all samples measured for a given note:



Ex. 1. Application principles for pitch modifications

The following diagram summarizes the entire method:



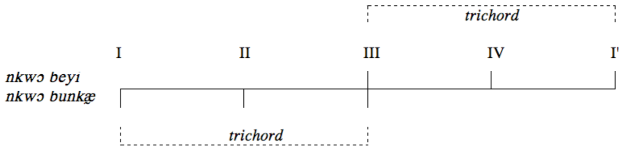
Ex. 2. Summary of the method

C. *Application of the experimental method*

The method was used in the field in three successive steps (during the Summers of 2000, 2001 and 2002), allowing us to progressively improve its efficiency and flexibility. From the first tests, it appeared that the Bedzan Pygmies gave considerable importance to the quality of the vocal timbre, obliging us to refine both the values attributed to the various parameters of the spectral analysis and the precision of those that we selected for transformation of the voices. Once this obstacle had been overcome, our task involved 1) developing hypotheses concerning the constitution of the scales, 2) preparing series of tests to confirm or reject these hypotheses and 3) interpreting the results of these tests after their submission to the Bedzan.

The main difficulty of this aspect of the research was designing tests for which the modifications could be sufficiently significant to draw a reaction from the Bedzan, without exceeding the limits of the system (because then they would lose any meaning for them, or the answers that they could give would be necessarily ambiguous). The problem can be summarized in these terms: how can we remain within a meaningful framework when we do not know what that framework is? The challenge was to constantly strike a balance between absolute strictness and the need to choose variables to be applied, without knowing the scope of these operations in advance.

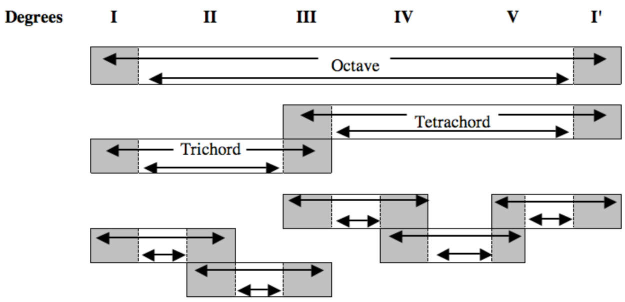
Our research was mostly done in the field, with the day-to-day analysis of the reactions of the Bedzan to the various proposals made to them guiding us in the development of new hypotheses, each time requiring that new tests be done. To summarize briefly, our approach initially involved work on determination of the field of realization of *each* of the degrees. We abandoned this procedure, which was long, time-consuming and finally not very profitable, to work in a broader manner on the comprehensive structure of the scale system. We first proportionally enlarged or compressed it, before doing the same type of operation not for each interval, but based on the trichord or tetrachord "framework-intervals", which seemed to be preponderant in the scale structure. The work continued with systematic application of the modifications to these framework-intervals within a tetratonic piece in which the two main voices each sang on one of the main trichords, each supplementing the other to reach the octave.



Ex. 3. *Degrees sung by the two main voices of the song nd&4O nd&4O, repertoire n4a*

This scale configuration allowed us to multiply the combinations between the two voices and to thereby test the limits of the trichords (I-III, II-IV, III-I'), those of the intervals found within them (I-II/II-III, II-III/III-IV, III-IV/IV-V) and also their *arrangement systems*. The results obtained, after submission to the Bedzan (twice and at both encampments), allowed us to uncover the principles that underlie the general structure of the scale system, which we then verified by applying these principles to other pieces with tritonic, tetratonic and pentatonic structures.

It turned out that the conception of the scales is based on *structuring intervals of less than an octave*. These are *trichords* (interval that itself contains two linked intervals) or *tetrachords* (interval containing three linked intervals). There can be relatively wide margins of realization for each of these framework-intervals, as for the intervals that make them up. These margins are however limited by a triple constraint related to 1) the upper and lower limits accepted for the trichords and tetrachords, 2) the upper and lower limits of the octave, formed by the juxtaposition of the framework-intervals and 3) by the minimum and maximum values that the intervals that make up these framework-intervals can take.



Ex. 4. Structuring principle of the Bedzan pentatonic scale

These fundamental rules are supplemented by the preponderance, for certain pieces, of a specific type of organization of the framework-intervals with respect to the *central core* formed by the degrees sung by the various parts of the polyphony (degrees III and IV in the example above).

The Bedzan's conceptual model is dynamic. Based on a limited number of rules, it applies a set of *reciprocal constraints*, the equilibrium of which must be respected in order to ensure the continuity of the system. It is probably the very simplicity of the system that makes it simultaneously so free and so complex, ensuring easy transmission from generation to generation.

III. OULDÉMÉ HOCKET POLYPHONY

The second part of our research focused on the scales of the music for flutes *aAèlèN* of the Ouldémé of North Cameroon. These instruments are played exclusively by groups of 4 or 5 women, each of whom holds a pair of flutes; their specificity lies in the system for tuning these instruments, which is done by addition or removal of a small quantity of water contained in the closed base of each flute. The musicians perform a hocket polyphony involving two levels: on the individual level, by alternation of vocal and instrumental sounds; on the group level, between their performance and that of their partners.

Our objective was to understand how the Ouldémé women conceive of their scale system, which a) shows substantial fluctuations in pitch between different versions of a given piece and b) does not fit the usual rules of reproduction of the scale system beyond the framework of the octave (Arom & Fernando 2002).

A. The experimental system

The idea here was to make an electronic system to simulate the flutes. This was done by the *Instrumental Acoustics* team at IRCAM, directed by René Caussé[6]. Several approaches were considered, ranging from sampling of real sounds to synthesis. The option chosen was the so-called *physical modeling synthesis* because of the possibilities that this procedure offers in terms of control by the instrumentalist, flexibility to changes in geometry (adaptability to the physical characteristics of each of the flutes), control of the timbre and also "playability" (reaction of the virtual instrument during playing).

The model made by the acousticians is based on the synthetic modeling of a resonator and an exciter. The resonator is modeled by a one-dimensional wave guide using fractional delay lines – to allow for continuous control of the pitch –, low-pass filters allowing for description of the losses due to radiation and to viscous-thermal effects. The effect of the addition of water can thus be easily taken into account. For the exciter, various elements are included, representing the interaction between the jet and the edge/side, the generation of vortexes at the edge and the turbulence noise added for which the proportion is directly linked to the speed of the jet (Lamoine 2001, Caussé & al. 2002).

In order to put the musicians in a situation that was as close as possible to their usual playing situation, the *artifact* flutes were made of bakelite tubes of proportions identical to those of the natural instruments. Each tube is equipped with a breath sensor (*Honeywell 26PC* differential pressure sensor) and two buttons to simulate the addition or removal of water from the tube. These various signals supply a sensor/MIDI interface that in turn provides the computer with MIDI input for the *pressure* and *pitch* input of the sound model. An implementation of this sound model (developed by Manuel Poletti) operating in real time in the MAX/MSP environment on a Macintosh PowerBook G4, allowed for the use of ten flutes simultaneously.

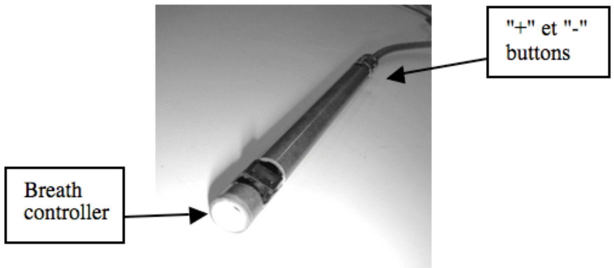


Photo. 1. Bakelite flute with breath-controller and buttons for tuning the pitch (photography: René Caussé, Ircam).

The interfaces programmed in MAX/MSP allow for verification of the status of each bit of MIDI information, for modification of the signal assigned to each channel and for control of the experiment. There are several distinct parts on the experiment control interface (Figure 6). The first, *Mixing*, is a "mixing table" with the ten corresponding channels. The second, *Tuning*, allows or prevents each instrumentalist from adjusting the tuning, with the two adjustment buttons on each flute: for the purposes of the study of scales it is worthwhile to be able to impose settings for certain instruments by preventing the instrumentalists from modifying them, and then to record the adjustments made by the other flutists with respect to this constraint. It is also in this part that the adjustment is made (by pressing on one of the two buttons on the flute) with displaying of the different values. Lastly, the third part, *Midi Sequencer*, allows for the recording of a sequence (recording of the various parameters and MIDI values) in order to analyze it thereafter. The recording makes it possible to replay the sequence in order to *offer the musicians a critical listening of the sequence*.

[6] The following people also took part in this research: Patricio de La Cuadra (Stanford, USA – guest researcher at Ircam), Jacques Lamoine, Manuel Poletti, Claire Ségouffin and Christophe Vergez.

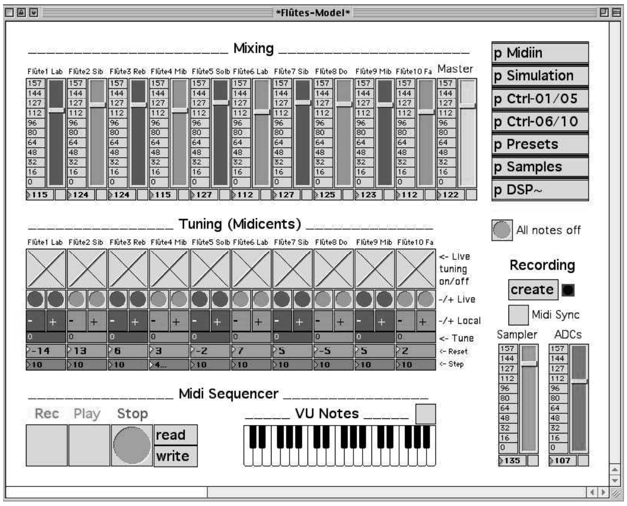


Fig. 6. Experiment control interface

B. The experiments

The experimental sessions were held in our laboratory in Paris, when a group of musicians came to France at the invitation of the Festival de l'Imaginaire7[7]. Four whole days, bringing together all of the researchers involved in this research program, were devoted to the study of the scales of the flute ensemble *aAùelùeN*.

1) Adaptation to the system

One of the unknowns was the reaction that the musicians might have to these new instruments. Once they had gotten over the first few moments of surprise and nervous laughter caused by the fear that they might not have the “know how” to play, the flutists picked up the instruments and, with no difficulty whatsoever, were shown by the acousticians how to make the adjustments so that the reactivity of the sound system would be as close as possible to their playing technique.

Photo. 1. Work session with Ouldémé musicians in Paris.

The flute adjustment — corresponding to one pressing of one of the two buttons — was set at 10 cents, an interval sufficiently small to allow for accurate tuning. After a series of tests, along with explanations from the researchers, the musicians adjusted to the system to the point that, as of the third day, they were speaking in technical terms, saying to each other: "Press three times", or: "Take out twice", to indicate the quantity of "water" that had to be added or removed to achieve the desired tuning. This point is actually quite important: it demonstrates that the Ouldémé women were able to estimate the size of the interval corresponding to two or three pressings, and thus that they were perfectly aware of the distance separating the pitch of the sound as it was set from the pitch that they sought.

2) The method

In order to determine the particular scale system(s) for this flute ensemble within the short time available to us, we chose a method that proved useful with the Bedzan; it involved testing the limits of the system by proposing various types of scales composed of intervals that could be progressively enlarged or reduced. But, unlike the experiments carried out with the Bedzan, the idea here was to suggest hypotheses that would be modified *by the musicians themselves*.

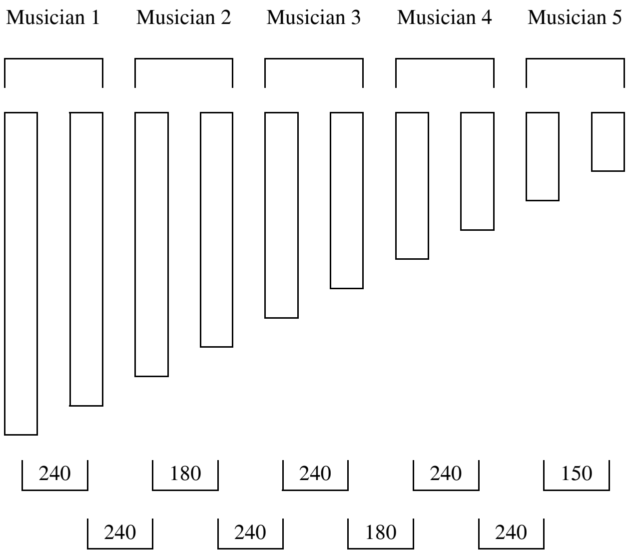
A strategy was quickly developed that initially involved giving the flutists scales composed of equal intervals, in order to observe their *retuning procedures*. Five scales of this type were offered to them: intervals of 300 *cents* (equitetratonic scale), intervals of 200 *cents* (equihexatonic scale), intervals of 240 *cents* (equipentatonic scale), intervals of 260 *cents* and intervals of 180 *cents*.

As the experiments progressed and the musicians became more familiar with the system, they checked and adjusted all of the tunings. Quite often they said that they wanted to listen to a session that they had just recorded – or an earlier session– again, which at the same time allowed for comparisons between the various retunings.

We then offered three scales with two interval sizes, the last two of which represented attempts to model the system: 200 and 300 *cents* (tempered pentatonic scale), 230 and 290 *cents*, and 240 and 180 *cents*.

C. Results

The results of this study appeared in two stages. The first series of results were used immediately, i.e. as the musicians modified the proposed scales. On this basis, we submitted a modeled version of the scale, which was accepted after the following modifications (in *cents*):



Ex. 5. First model of scale system for flute ensemble

[7] *Maison des Cultures du Monde*, 101 bd Raspail, 75006–Paris (www.mcm.asso.fr).

However, a thorough re-examination of all of the information provided by the modifications reveals some contradictions — for example it was impossible to define coherent realization margins for the intervals — and the model obtained was only descriptive.

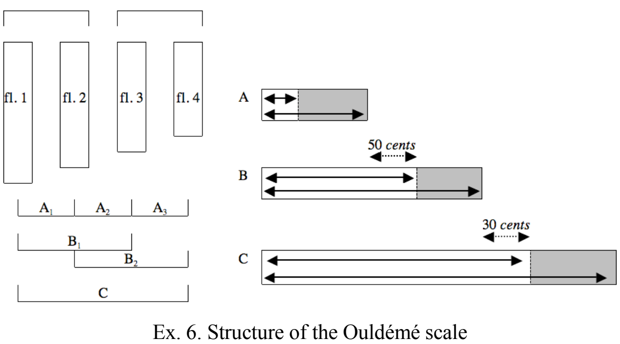
In light of the most recent work with the Bedzan and the principles that were determined from this, there was a complete reinterpretation of the experiments. We were thus able to determine the scale system of the Ouldémé flute ensemble, which has some points in common with that of the Bedzan: the Ouldémé scale is governed by interval relationships subject to *reciprocal constraints*, the trichords and tetrachords playing a leading role in the conception of the system.

The scale revealed does have many specific features however in that:

– there is no complementarity between two consecutive framework-intervals ending at the octave; the octave is therefore not the reference interval within which the scale is organized. On the contrary, there is a translation of a smaller structure organized according to a single tetrachord, this configuration being translated from one pair of flutes to another.
– nor is there a *central core*.

The scale system is based on a single type of interval for which the realization margins are extremely wide (ranging from about 120 to 320 *cents*). This interval is however subject to a double constraint involving the limits of the trichord and the tetrachord. It is thus a system governed by a single type of interval with regard to the space between two conjunct degrees ("simple interval"), but also by the combinatory of the three types of intervals that it generates (simple interval, trichord and tetrachord) with regard to its overall structure. It should be noted that while each of these three intervals can have quite different realizations, they are clearly in contrast within the sound *continuum*, because they have no common "boundary". There can be no ambiguity, neither between the simple interval and the trichord, because their respective upper and lower limits are 50 *cents* apart, nor between the trichord and the tetrachord, separated by 30 *cents*. The following example summarizes the scale structure used by the Ouldémé flute ensemble.

Simple interval → A_1 *or* A_2 *or* A_3
Trichord → $B_1 = A_1 + A_2$ or $B_2 = A_2 + A_3$
Tetrachord → $C = A_1 + A_2 + A_3 = A_1 + B_2$ or $B_1 + A_3$



Ex. 6. Structure of the Ouldémé scale

The intervals greater than the tetrachord are not significant, because the system is based on the relationships defined by the spacing in the sound *continuum* of the four consecutive degrees. Thus the size of the interval that covers 5 consecutive degrees (pentachord) can be greater or equal to that of the hexachord, which corresponds in a "standard" pentatonic system to the octave, *which is not operative here* and which can take values ranging from 1030 to 1320 *cents*.

IV. EXPERIMENTAL IMPACT AND RESOURCES

As we have seen, when technology becomes a medium of communication between researchers and traditional musicians, it is important to identify the type of information sought and the procedures to be used. In other words, it is essential to know *who transmits what type of information through what medium*. Technological experimentation must be adapted to the context of the musical practice of the culture being studied.

While our experimental procedures involve interaction between researchers and the local musicians, there is another very important feature, i.e. the interaction among the musicians themselves, in the form of disagreements on certain points, which reveal precious information that might otherwise have escaped the researchers' attention.

It is clear that this type of experimental procedure completely changes the relationship between researchers and musicians, who are no longer mere "informants" but rather collaborators in the scientific process.

Through the use of new music technology in an experimental context, traditional musicians can materialise mental templates of their own culture's musical system. Musicians find themselves at the active center of the experiment, *a fortiori* with a perspective geared to *model construction*, at the same time as the researcher. They are able to distinguish between their concept and the musical realisation of this concept. In this situation, the "machine" is not only an experimental tool, but also a special place where a virtual and conceptual reality is projected. In this way, musical technology comes to the aid of theory to the extent that the bearers of diverse musical traditions can express their knowledge and make it explicit.

Our experimental procedures allow for a prepared expectancy of very particular events, namely the emergence of a critical consideration by indigenous experts of their own traditional artefacts.

The exercise of judgements of acceptance or rejection involves the reactivation of cultural criteria related to the complex of systematic musical features. We thus have a privileged opportunity to witness critical and normative competencies, concretely and effectively applied to cultural devices.

We have seen that the researcher has to adapt the technology to the theoretical universe of the societies under study, to choose – according to this universe – the media form most successful for transmitting the information, and finally to account of the consistency of this information through *modelization*. The indispensable interaction between musicians and researchers requires simulation of the traditional musical practice to the extent possible : for example, bars of wood fixed to the keyboard of a synthesiser act to resemble those of the xylophone. A number of instruments (percussion, wind, and plucked string instruments) can be equipped with MIDI captors, permitting a digitalized treatment of the playing actions, gestures, and intentions of traditional musicians. Thus, each traditional instrument can potentially have the same function as the digital instruments, even if for the time being these applications seem to be prototypical.

The rapid evolution of musical technology, and in particular its miniaturisation, allows us to foresee the introduction of experimental research in most of the domains of ethnomusicology, thus allowing the discipline to contribute a truly comparative dimension to the cognitive sciences ; music learning, perceptual mechanisms, conceptual representation, relationships between concept and realisation, are all inherent to the musical practice of a culture.

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Experiments in the field are opening up new avenues of investigation, which have brought the initial object of the research into a much broader dimension. The various types of interaction provoked by our experimental systems are clearly of value for studying diverse areas of cognitive sciences applied to culturally homogeneous societies, particularly with regard to the capacity for adaptation to an outside technology, the psychology of perception, the difference between perception and conception, and the relationships between these various domains and cerebral neurobiological processes.

Through a study dealing with music then, our methodology *revealed forms of knowledge that, by their nature, cannot be verbalized.*

REFERENCES

[1] S. Arom, "L'étude des échelles dans les musiques traditionnelles : une approche interactive", Analyse Musicale n° 23, 1991, pp. 22-24, Paris: SFAM.

[2] S. Arom and N. Fernando, "L'ethnomusicologie est-elle condamnée à rester une science 'molle' ?", in Observation, analyse, modèle : peut-on parler d'art avec les outils de la science ?, J.-M. Chouvel et F. Lévy, ed., 2002, pp. 423-445, Paris: L'Harmatttan/IRCAM.

[3] S. Arom and F. Voisin, "Theory and Technology in African Music", in The Garland Encyclopaedia of World Music, Ruth Stone ed., Vol. 1. Africa, 1998, pp. 254-270, New York: Garland.

[4] S. Arom, F. Voisin and G. Léothaud, "Experimental Ethnomusicology : An Interactive Approach to the Study of Musical Scales", in Perception and Cognition of Music, Irène Deliège & John Sloboda ed., 1997, pp. 3-30, Hove (U.K.), Erlbaum, Taylor & Francis.

[5] P. de la Cuadra, C. Vergez and R. Caussé, "Use of physical-model synthesis for developing experimental techniques in ethnomusicology -

[6] The case of the Ouldémé flute", Proceedings of the International Computer Music Conference, Göteborg, Suède, 2002, pp. 53-56.

[7] R. Caussé, P. de la Cuadra, B. Fabre, C. Ségoufin and C. Vergez, "Developing experimental techniques and physical modeling for ethnomusicology project on Ouldémé flutes", in Proceedings of the Forum Acusticum (European and Japanese Symposium on Acoustics), Séville 16-20 septembre, CD-Rom MUS-06-014, 2002.

[8] N. Fernando, "New perspectives for interactive field experiments", The Yearbook for Traditional Music (YTM), Stephen Wild, ed. vol. 34, 2002, pp. 163-186, ICTM.

[9] N. Fernando, "Expérimenter en ethnomusicologie", in L'Homme, B. Lortat-Jacob and M. Olsen, eds., Paris: Mouton, n° 171-172, 2004, pp. 285-302.

[10] J. Lamoine, "Etude des propriétés d'un jet turbulent soumis à un champ acoustique transversal", Stage de Maîtrise de Mécanique, Université Paris XI, Orsay, 2001.

[11] F. Marandola, "L'apport des nouvelles technologies à l'étude des échelles musicales d'Afrique centrale", in Journal des Africanistes, Vol 69-2, 1999, pp. 109-119, Paris.

[12] F. Marandola, "Les principes de fonctionnement du système pentatonique", in Forum de discussion 1, Musicæ Scientæ, 2000, pp. 97-106, Liège: ESCOM.

[13] F. Marandola, Scala, in Forum Ircam 2003, software + documentation, Paris: Ircam, 2003.

DISCOGRAPHY

N. Fernando and F. Marandola, 1 CD, Cameroon - *Flutes of the Mandara Mountains*, collection OCORA Radio-France, C 560110 (German, English, French), 1996.

N. Fernando and F. Marandola, 1 CD, Cameroon, *Bedzan Pygmies from the Tikar Plain*, collection Inédit, W 260095 (English, French), 2000.

N. Fernando and F. Marandola, 1 CD, North Cameroon – *Music of the Ouldémé, To the rhythm of the seasons*, collection Inédit, W 260104 (English, French), 2002.