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The Physical Model as Metaphor for Musical Creation “pico..TERA”, a piece entirely generated by physical model

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Abstract

We will present in the first part of this paper a musical work, pico..TERA, recently created by the author, which is a 290-second piece entirely generated by one (non real-time) run of a complex physical model “orchestra”. With this work, we will show how a musical piece can be created, from its micro- to its complete macro-structure by the means of a physically-based formalism. Then, we will identify the concepts within the piece that introduce this new dimension of “musical construction”. From a theoretical analysis of the specific examples and applications in the piece, we will induce and introduce a general conceptual framework for musical composition through physical modeling and will explain in the last section the fundamental “paradigm shift” to which it corresponds.

1 Introduction

If we refer to the (French) etymology of “compose” (*com-poser: poser ensemble*, put together) we can say that, strictly speaking, “composition” is only one way to create music. Indeed, a musical structure (and more generally any complex structure of events that can be perceived by our senses) is made of assembled simpler entities that can be put together either in a completely free way or by a generative process: an abstract rule, an automated (physical, mechanical, numerical...) process, a dynamic gesture, etc. Conversely, these entities themselves may be produced by a process (for example the individual notes from a given instrument) or by “com-position”, like the traditional technique of treating, copying and pasting parts of signals in electro-acoustic signal editing.

Although the aim of this paper is to demonstrate that the physical modelling approach can be used even for compositional purposes (strictly speaking) we prefer to speak of musical *creation* or “*construction*” in this larger conception and envisage

here the question of musical construction thanks to physical modeling.

And in order to avoid another confusion, we insist on the fact that it is not the trivial question of musical composition using sounds obtained by physical models, but of the use of the physical model for the complete process of musical construction, from the microstructure (the sound material) to the macrostructure (the complete piece itself).

2 pico..TERA – “a junction between scales”

This piece has been created thanks to the CORDIS-ANIMA formalism [Cadoz, 1993] and its graphical user interface GENESIS [Cadoz, 1999] in a non real-time application. Let’s review here just the basic concepts that will be necessary to understand how the entities involved in the piece are conceived and built.

2.1 CORDIS-ANIMA and GENESIS

CORDIS-ANIMA is a language that proposes to model and simulate physical objects as networks where the nodes represent punctual material elements and implement their simulation (for example masses) and where the links represent and simulate force interactions between these elements (for example linear visco-elasticity or every non-linear physical interaction). GENESIS is the graphical user interface that allows to easily design and experiment with these models for sound synthesis and musical purposes, and to create sound files (mono-, stereo- or quadriphonic) of any duration from the physical models designed. A model can be of any complexity (including several thousands of elements).

For this piece, we use the set of very few basic elements described here after.

The **MAS** element is a punctual mass moving on a one-dimensional axe (OX) and characterized by its inertia (M). It can be given initial conditions at the beginning of the simulation: an initial position (X0)

and an initial velocity (V_0). The MAS module, as any material module in CORDIS-ANIMA, calculates for each sampled time n , (corresponding to the sampling rate), a $X(n)$ position in response of the (two) previous positions and to the sum $F(n)$ of the input forces.

The **SOL** element is a MAS with an infinite inertia, that can be given an initial position, but that cannot move.

The **REF** element is a visco-elastic (spring-damper) interaction connected between two material elements and calculating two opposite forces addressed to them and depending in a linear way on the difference of their position / velocity and of an elasticity parameter (K) and a damping parameter (Z).

A **CEL** element combines SOL-REF-MAS in a single embedded module and is often used for more synthetic representation.

Only two non-linear interaction modules, the simplest in this category within the CORDIS-ANIMA language, are used in the piece:

The **BUT** module is an asymmetric REF. Oriented from a first toward a second material element, and according to a threshold (S), the corresponding spring-damper is active only when the position (X_2) of the second element is less than the position (X_1) of the first plus the threshold (S). This element is the basic means to simulate collision between particles.

The **LNL** (non-linear link) module allows to define non-linear interactions by direct design of the $F(X)$ or $F(V)$ characteristics thanks to graphical or algebraic definitions. It is used for example for the basic simulations of the plectrum-string, bow-string, reed-mouthpiece interactions, etc.

The last element is the **SOX** (X position output) that allows addressing the movements of any chosen material element to one, two or four loudspeakers.

Only these seven elements have been selected, parameterized, combined in the piece thanks to the various elaborated modeling and editing functions of GENESIS.

2.2 Components of the piece

The piece is generated by a single complex model, an “orchestra”, made of a set of vibrating structures, “wind simulators”, elaborated instruments, virtual instrumentalists, “leaders” and listeners that are assembled and combined in various interacting situations in a single “room”. We first describe below the main components implied in this “theater”.

Instrumental structures

An instrument in the CORDIS-ANIMA context is basically made of Vibrating Structures (VS) that can be free, attached to SOLs (fixed points) in several

manners, linked to bridges and soundboards, and that can be put in vibration in different manners by an “instrumentalist”.

Vibrating structures are sets of MAS and/or CEL linked by REF, BUT or LNL that can be attached by one or several of its elements to one or several fixed points that represent the edge conditions. The more general form corresponds to a general network where each component has its own parameter values. The intrinsic properties of the VS depend on its two characterizations: its network structure and the set of parameters. GENESIS offers various elaborated ways to create and edit the both. Large ensembles of elements can be managed through sophisticated rules allowing to design macro topologic networks and macro-parameters. An analysis and tuning module within GENESIS can identify all the vibrating modes of any linear structure and to transpose the spectrum in order to fix the frequency of one of its components to a determined value.

A basic VS is for example the string, made of series of MAS-RES assembled in a line. It is possible to tune and play genuine string sounds from such a basic model. But in this piece, we left this kind of well-referenced object aside in order to investigate in another way the timbre space of the CORDIS-ANIMA universe. We adopted a pragmatic and systematic investigation focussed on the basic topologic properties of the VS networks rather than on an ideal expected spectrum result. Thus, we discovered interesting properties of VS, not only as to their individual identity but also in their combination potentiality. Among the various topologic shapes investigated, we kept only three categories that constituted our “basic material”: the CEL (the simplest), the RING (which is a string closed on itself and with no attachment points) and the TRIANGLE (fig. 1). The musical properties of the last, when attached on two of its corners are quite fascinating and we will describe below how we used them in our musical approach (sound example 1).

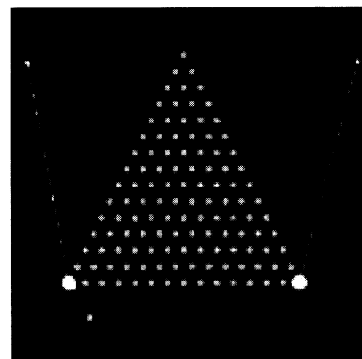


Figure 1 –TRIANGLE

Free particles in a box – the “maracas” metaphor

One can think of the sounding matter, at the scale of vibrating structures, in two opposite ways: contiguous or not. We can say that a string or any vibrating shape is a set of linked particles. Using the CORDIS-ANIMA elements without any partiality, we can use BUT instead of REF in the VS designing. Doing that within a string structure fixed on its two extremities is equivalent to enclose a set of free particles in a little box, each particle colliding with its neighbor when moving. When the number of particles is greater than three, their movements are erratic. Within a signal approach, this can be seen as the basic way to generate noise. But within a physical model approach, it is relevant to consider this process as a dual of the contiguous matter elements. This opens a new original way of understanding and creating the elementary vibrating objects. There is a relevant correspondence, with significance at the perceptive level, between contiguous structures (like the ones containing only REF elements) and non-contiguous, where several or all of the REF elements have been replaced by BUT: for a string (for example), the damping properties are in both cases determined and controllable by the Z parameter (of REF or BUT) and the spectral center of gravity is, also in both cases, determined by the K parameter (of REF or BUT). By reference to the maracas, which corresponds very closely to this physical situation established in a specific scale, we used to call this approach the “*maracassing*”.

In the piece, we used such a model (see fig. 2) to create wind sounds. In our application, we used two nested levels of “maracassing”: a first maracas is made of 8 master particles and each master particle is itself a “sub-maracas” made again of 8 smaller particles. By this way, we can generate noisy sounds with two scales of random variations, one at the audio level and one at a sub-audio level, generating slow erratic fluctuations in the energy of the signal (sound example 2).

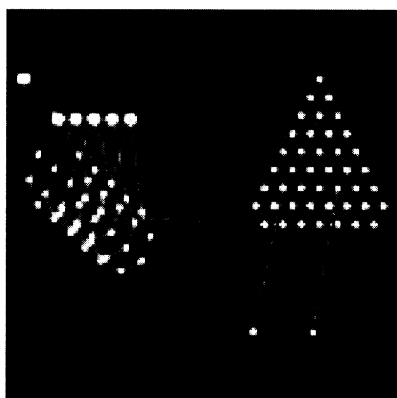


Figure 2 – Wind and maracas and TRIANGLE

Bridges and soundboards

They are the means to complete instruments from VS. In the real world, two elements play important roles: the soundboard, which transmits, thanks to an impedance adaptation, the vibrating energy to the aerial environment, and the bridges, which is the energy link between the VS and the soundboard, but which is also the means to associate several VS in a single instrument. A very simple, but efficient way to model a bridge within CORDIS-ANIMA is to replace the attachment points (the fixed points of the VS) with a CEL element whose parameters are fixed to specific values: the inertia M (of the CEL) must be great (say 100 times) in comparison to the inertia of the VS; the K value must be maximal (but less than the critical divergence value) in order to give to the CEL oscillator a frequency mode near the maximum possible value (20Khz). The Z value must be fixed at the critical damping value. In this way, we design, in fact, a second order low pass filter. Attaching several VS to the same “bridge”, we effect the summation of vibrating phenomena. The bridge in CORDIS-ANIMA is the transposition in the physical modeling context of signal addition in the signal modeling approach.

The soundboard can, then, be any structure (in the same conception as the VS), designed with the specific modes we wish.

Hearing the instruments

It is possible to hear the instrument (when vibrating) by sending the movements of one (two or four) of its points to one (two or four) loudspeakers. The points may be on the VS itself, on the bridges, on the soundboard. It works but it corresponds, in a real scene, to place our eardrums on the instrument. That is not completely realistic. In the real world the sounding objects are in an aerial environment, generally in a room. So we might give a counterpart to this environment. Strictly speaking, it is possible to adopt in front of the aerial environment and the room the same attitude as with the previous parts of the scene: to model them as networks of interacted particles with the appropriate parameters. But it might take a lot of calculation. In several studies and in particular in the piece, we adopt a very simple but efficient bias. We introduced four bridges, that can be seen, physically, as bridges put on the loudspeaker membranes. Then we linked all the points or set of points we wanted to listen to (from the VS, the bridges or the soundboards) with a FRO element (damper only) with a very low value (in order to not modify the properties of the instruments). In this way, obviously, the physical distances between instruments and listener are totally ignored but their respective intensities can be adjusted by the various Z parameters in the corresponding FRO elements. Also, it is possible to send to these bridges the vibrations of a “free-floating” instrument (an instrument with no

fixed points and that has a continuous displacement in the space) by linking two separate points of its VS to the same bridge with two opposite FRO elements (with a negative and a positive Z value). This is not physically consistent but very practical since several VS without fixed point, like the RING we use in the piece, have very interesting sounds.

Playing the instruments

Giving initial position or velocity to one or several MAS in the VS put them out of their equilibrium state. So, they vibrate and return to rest after a certain time depending on the Z values within their structures. But this is a quite rough way to play instruments: all the notes will start together, at the beginning of the piece. Within the non-real time use of CORDIS-ANIMA, that is quite practical for numerous purposes, it is nevertheless not possible to really play the instruments. Never mind! We have just to simulate instrumentalists. Apologizing for that (an instrumentalist is not reducible to a physical model, of course!), we can at least try to simulate the simplest of their physical behaviors thanks to suitably built CORDIS-ANIMA networks. So, we will describe now the second kind of metaphoric approach used in the musical construction within GENESIS: the instrumentalist metaphor.

However, one cannot do this without considering an essential but ambiguous element, which can be understood either as a part of the instrument or as a material extension of the instrumentalist: the "exciter" that is for example the mallet of the percussionist (or of the percussive instrument) or any other object insuring the energetic link between the gesture of the instrumentalist and the VS of the instrument.

The Exciter

The simplest situation can be defined considering a single interaction between instrumentalist (IST) and instrument (ENT) and more precisely between one MAS belonging to the first (MAS-IST) and one belonging to the second (MAS-ENT) and just assuming for the moment that MAS-IST is moving along its own axe according to its own intention. Due to the fact that the mechanical movements of these two systems are in exclusive bandwidths (0 to less than 20Hz for the first and more than 20Hz to 20KHz for the second) the energy transmission from the first to the second need, between them, a non-linear interaction. In the real world, this corresponds to the basic categories of excitations: by striking, plucking, shaking, bowing and blowing. Each of these interactions can be modeled thanks to a non-linear element within the CORDIS-ANIMA tool-box. We studied for many years all these kinds of excitation [Florens 1990, Fourcade, 2001]. For the piece, we used only two simple interaction models: striking (achieved with a BUT), and plucking (achieved with

a LNL). The sound quality of the percussion with the BUT element, when the inertia of MAS-IST is less than that of MAS-ENT is entirely (and exclusively) determined by the frequency mode of the oscillator corresponding to the MAS-IST / BUT during the contact phase [Fourcade 2001a, 2001b].

The pluck interaction, achieved with a LNL (see fig. 3) involves a $F(\Delta X)$ characteristic that gives no interaction force if the ΔX distance between MAS-IST and MAS-ENT is more than a threshold value (positive and negative) that corresponds to the maximum deformation of the plectrum, a maximum force when MAS-IST and MAS-ENT coincide ($\Delta X=0$), and a decreasing force when ΔX goes from 0 to the threshold value. Although very simple, this model allows the basic plucking actions with rich variants and can accurately produce the micro contacts and rebounding phenomena (and the corresponding sound effects) when the string (the VS) interact with the plectrum.

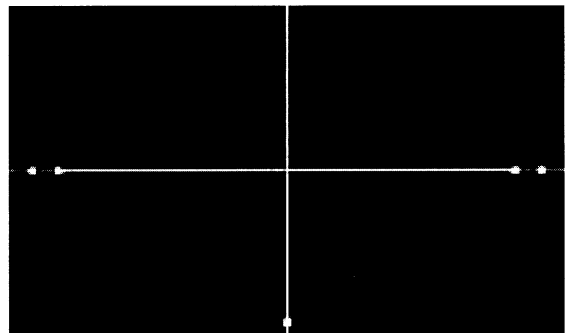


Figure 3 – Plectrum modeled with a LNL

The “instrumentalist”

The simplest instrumentalist (I apologize again!) can be represented by a single MAS moving from a certain distance to the VS and linked to it with an exciter. In this case, the MAS can be considered at the same time part of IST and part of the exciter. If the link element is the BUT (striking), the MAS will reach the VS, remain in contact through the spring and damper interaction during a short time, and then rebound from the VS and go back where it came from. If the link is a pluckLNL, the MAS will reach the VS, interact and displace the VS contact point and pass through, continuing its travel.

These two cases can be understood as elementary instrumental gestures. According to this view, one can define two first elements of a gesture language in the context of physical modeling:

- the energy of the gesture, defined in a kinetic way or as the quantum of movement $M \cdot V_0$
- the action time of the gesture that is the time MAS-IST takes to run from its initial position X_0 to the VS, $T = V_0 / X_0$

In GENESIS, we designed a specific language level that allows giving the input (physical) data from gesture concepts. Thank to it and to appropriate interface windows, we can design a gestural score giving such energy and action time values for a set of MAS that will play a sequence of events. Having no particular limit on the definition of distances, it is possible to decide that an event will occur 10 minutes after the instant 0 of the simulation.

Of course, the “instrumentalist” MAS can be sent to any MAS within the complex instrument we want to play. For example, a single string, or TRIANGLE can be excited on any of its elements, producing a variation in the relative weights of its spectral components.

Defined here from simple examples, this approach can be generalized in a formal concept: in the physical model context, event control (where events are defined as a quantity at a certain time) can be entirely represented as a set of particles:

- acting on a specific point of the instrumentarium (orchestra)
- having a movement quantum
- acting at a definite time.

More sophisticated instrumentalists

Although we cannot, fortunately, envisage simulating a real living instrumentalist (far from us such an intention!), we can nevertheless increase the gestural vocabulary in this metaphoric approach. The MAS-interaction paradigm, indeed, is not exclusively reserved for sound production. It allows to model any dynamic phenomena produced by interacting objects. Position, movement, velocity, inertia, elasticity, viscosity and non-linearity are states and properties that can be applied to a wide variety of entities (even to certain life-like features or beings, not only in

metaphoric senses). Thus, we can use these concepts to create virtual gestures presenting quite rich properties. We will introduce below the main virtual instrumentalists we used in the piece.

The “beater”

Linking with a REF the previous MAS-IST to a SOL, we obtain of course an oscillator. But we can give it a K parameter that gives, combined with the M parameter, a low frequency to the oscillation, say for example 1Hz. Equipped with a pluckLNL, this low oscillator will play a repetitive plucking (beat=60) on the VS it is linked with. If we put a non zero value for Z, this beater will be tired after some time and will stop playing.

The “snake”

Probably all the networks that are relevant for acoustic vibration production are not available (even correctly transposed), or do not cover all the relevant gestures (and more generally temporal figures), and we must consider that at this temporal scale, we have to understand new phenomena. But certain cases are nevertheless of obvious interest. For example, building a string with heavy masses and low stiffness parameters gives slow waves that can be perceived as a global gesture “undulation” or as the waves of a natural phenomena (sea or wheat field under the wind). In this way, we built in fact a “snake” along which we installed plucking LNL acting on various strings of a zither (fig. 4). Choosing carefully the correspondence between the successive segments of the snake and the specific strings of the zither, and setting initial conditions at the head (for example) of the snake, we obtained elaborate melodies.

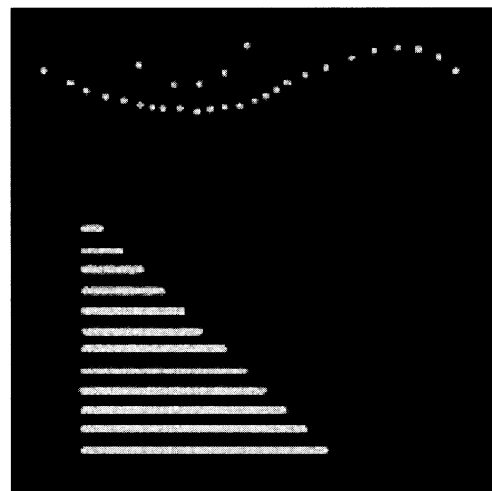


Figure 4 – The “snake”

The “domino”

Replacing the REF within the snake by BUT, we get a chain of MAS that will collide each other. Starting with all masses in a rest state and striking the first, we will activate a cascade phenomena where each MAS starts moving a little delay after its left (or

right) neighbor. The different delays can be adjusted through the threshold parameter of the BUT element. This is a way to add a “rhythmic” definition to the previous “melodic” one.

In the piece, we used a “domino” to create a salvo of high pitched short and fast sounds with a pitch glissando (sound example 3). We created series of rings of increasing sizes (number of MAS in the rings) and excited them with striking BUT attached to each element of the domino (fig. 5).

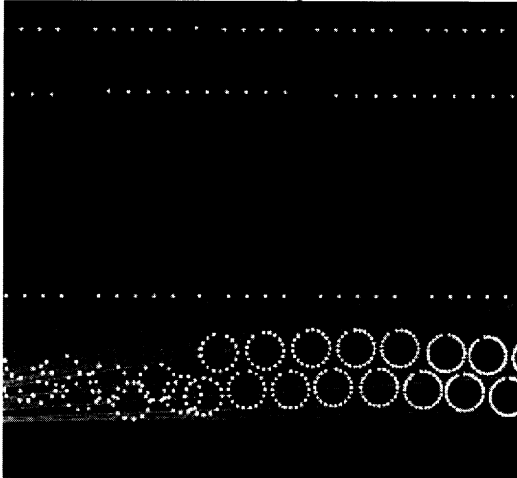


Figure 5 – The “domino” playing a set of RINGS

These three examples are given here to introduce and illustrate the idea of construction of complex macro temporal events with MAS-interaction networks. They don’t represent a complete view of the possibilities, but they are quite complementary and let us anticipate the possibility of a general formalism, extending the first bases given in the previous section, for the macro-temporal musical construction within the physical modeling. This formalism is built from an abstraction of the “instrumentalist” and “gestural” metaphors and is supported by a suitable level implemented in the structure and parameter editor in GENESIS.

Hierarchy and interaction

One can think that there is a non symmetric (hierarchic) relation between the instrumentalist and his instrument: the former can play the later, but not the contrary. If our previous “beater” plays a string, or any other instrument in striking mode (instead of plucking mode), the collision between MAS-IST and MAS-ENT modifies the movement of the beater. Thus, in this case, the instrument “plays the instrumentalist” and modifies its beating rate.

Instrumentalist – instrument hierarchy

It is possible to introduce, like in the real instrumental situation, an intermediary component that remedies that. First, let us give a great value to the inertia of MAS-IST (say 100 time the MAS-ENT), and also a great value to the corresponding K

in order to keep the same value (1Hz) for the beat frequency. Then, let us add a REF-MAS to the MAS-IST in such a way that its own frequency is the same as that of the beater, but with the critical value for Z (fig. 6). Let us put now this ensemble at a distance that is nearly the same (a little less) as the amplitude of the beat oscillations. We will obtain a strike each time the MAS-IST equipped with its small drumstick reaches the VS but this time, the oscillations of the beater will remain perfectly stable and regular.

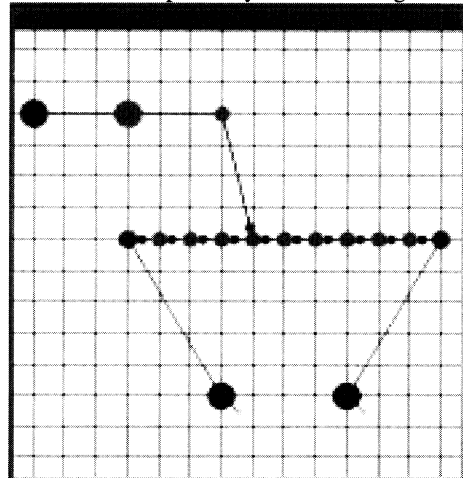


Figure 6 – Instrumentalist with a drumstick

Instrumentalist – instrument symmetry

And now that we know how to restore the normal hierarchy, we can change our point of view and envisage reinstalling symmetry by decreasing progressively the values of the parameters in the beater oscillator. Doing that we enter a fascinating universe: the beats are almost regular, but (1) they shows very life-like fluctuations, and (2), after a sufficient time, the beater having given all its energy to the instrument, stops playing. This corresponds better to a natural situation in which the entities, even in a hierarchic relation, are always in bi-directional relation. The traditional musical thinking generally does not envisage such interaction between elements at this time and structure scale. But it might be an inherent limit to the structuralism thought.

Another example of this kind of situation, in other conditions, is the case of a similar beater playing a VS with a plucking LNL. Simulating a beater having a 300 meter long arm and in its fingers a normally sized plectrum plucking a normally sized string, and adjusting (thanks to computer precision) the displacement amplitudes of the arm in order that it just reaches the string, we obtain very amazing life-like accentuation in the sequence of successive beats (sound example 4). This can be obtained only when the ratio between the scales is great enough and can be explained by the subtle phases occurring in the position of the vibrating string at the moment when the plectrum encounters it. This singular situation, which can be implemented in many variants, lets us

understand that there is something quite fundamental in the possibility to make very different sized spaces to meet and to interact. One can recognize here one of the main features within the chaos as morpho-genesis theory: the sensibility to the conditions. We used this principle (which is not so easy to master!) in the piece and decided at this moment for its title.

The “leader”

Let us introduce now a second kind of hierarchy. A MAS can be used as a bowing exciter when we link it to a string with a suitable LNL (a non-linear viscosity link with a characteristic corresponding to the force-velocity relation in the bowed string structure – see fig. 7). But if we give the MAS an initial velocity, this virtual violinist will play its unique note from the beginning of the piece until its end. That may be quite unpleasant. A simple way to change this is to introduce a new (and last) protagonist: a “virtual leader”. In this universe, a “leader” is, in its simplest definition, a MAS (!) at least one hundred time greater than the instrumentalist he conducts and that is simply thrown from a suitable distance at the instrumentalist. It works in the same way, but at an upper hierarchic level, as the first elementary instrumentalist we introduced above. In the present example, the leader MAS linked with a BUT to the violinist MAS will strike it at a time depending on the difference of their respective initial positions and will make it begin playing at this time.

We can understand now that a leader can conduct any instrumentalist, for example the “beater”, and that he can conduct several instrumentalists simultaneously. We can understand also that it is possible to build complex leaders in the same way we built complex vibrating structures or instrumentalists, that we can have... several leaders and also leaders of leaders and finally that we can preserve a strict hierarchy between the leader and instrumentalists or between the different leaders. But we also understand that we can have a more symmetrical society in which the instrumentalists can also conduct the leaders. It was when we experienced this last case that we encountered the more interesting and life-like results. This is enough now to understand the most important: we have here a general way to create any complex multi temporal scale events. We introduced it with the help of practical metaphors but it can be formalized if necessary through a very serious language and managed through very elegant elaborated interfaces.

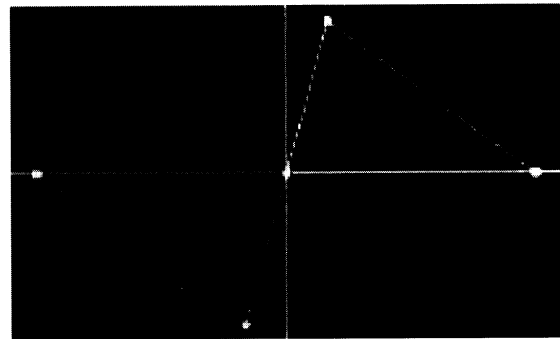


Figure 7 – Bowing LNL characteristic

3 The construction

The construction of a piece within this physical modeling approach consists first in the building of two categories of components: the “instruments” and the “players”, corresponding to two different temporal scales, the microstructure and the macrostructure scales. For each, we have to “compose” objects, i.e. to put together and link elements that are defined out of the time: the different MAS and interactions. These objects are not temporal objects but they generate temporal events. Composing the objects, we have a total freedom in the choice of their properties. On this freedom axe, we can apply arbitrary choices or rules of any kind. For example, for the set of 8 TRIANGLES we used for the “harmonic” background of the piece, we used a pragmatic law founded not on the pitches but on the topologic properties. Let us detail this:

“Harmony of the causes”

The TRIANGLES are characterized by their number of lines; 15 lines for the larger one. One can know their spectral structures, using the analysis module in GENESIS. And it is possible to tune the TRIANGLES in order to constrain each of them to correspond to a given pitch in a chord. Having tried this, we noted that the chords sounded very poorly. Indeed, this “composition” is not consistent since it put together features that are strangers to each other. Then, we adopted another approach focussed also on simple ratios, but not on the pitch: on the topologic sizes. By giving to the TRIANGLES, made with the same “matter” (values of M, K and Z parameters) several sizes in simple ratios (15, 12, 9, 7, etc.), we obtained chords that have nothing to do with any classical chord (the frequencies are in quite complex relations) but that sound consistently in the various expositions we can do. The consistency is here a result of a simple law applied to the physical properties of the objects, i.e. to the cause rather than the effect.

In a second step, we have to compose the “orchestra”, that is to put together the different components (instruments and players). Again, the

choices can be arbitrary (they must only guarantee that the assemblage works). In this area, we can create all the combinations that correspond to our expressive purpose. But one can notice that it is not yet a temporal construction. Temporal features can emerge from this assemblage but they are not the explicit level at which we act. One will notice also that the structural level can be very intimately intricate. For example, the TRIANGLES are used simultaneously in two different functions: in one case they are vibrating structures attached to bridges from which the signals are picked up and sent to the loudspeaker bridges, and in the other, they are the soundboards for wind generators. The “players”, then, act on two different levels: on the wind generators and on the TRIANGLES.

And finally we have to compose the basic trigger events: the individual MAS that are given a movement quantum and an initial position, determining the time and the amplitude of the temporal events they start in various point in the global orchestra structure. For these trigger elementary gestures, we can choose any arbitrary values according to our expressive intention. Notice that in a real-time context, these events will correspond exactly to the kind of the instrumental gesture we called the “excitation gesture” [Cadoz, 2000]. Notice also that these trigger events will start simple temporal events, for example when they are applied to simple instruments, or complex ones if they play the role of what we call “leaders”, acting on complex “instrumentalists”.

The complete GENESIS room we built for *pico.TERA* is given in the fig. 8, below.

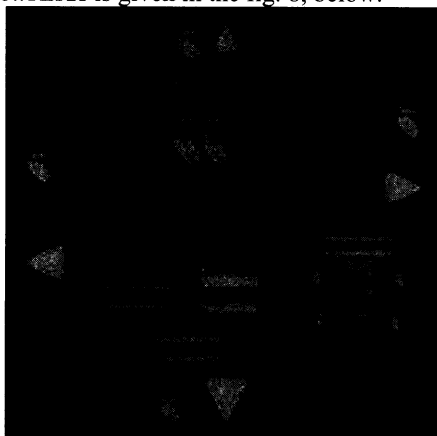


Figure 8 – The *pico.TERA* “room”

4 Conclusion – a paradigm shift

We demonstrate that it is possible to create a synthesized sound sequence of the duration of a musical piece within the physical modeling paradigm and without any post-treatment. Independently of the musical result, which everybody can appreciate or not, we state, through an ensemble of examples, that all the construction processes (generation and

composition) are possible at all the different level of the musical structure. By its principle, the physical modeling approach offers new ways of complex and relevant structuration with an intimate relation between the different hierarchic levels and with a new concept: the managing of interactive meetings between the different scales. The scales themselves are not constrained to be though exclusively in terms of temporal structures but they can be either temporal, phenomenologic or causal. We demonstrate also that a unique paradigm founded on a very small number of concepts and basic functions can be used for musical construction, from the micro to the macrostructure without rupture.

But the most important and new feature, which truly corresponds to a paradigm shift in the musical creation process, is that we moved the focus: in a generalization of the starting point of physical modeling, which was “to think and to act on the causes rather than of the effects”, which has demonstrated its relevance for many years, we can now apply it to the entire musical creation purpose. This puts forth a strange question: what is the cause of a complex musical event? If we remain with a skimpy understanding of the notion of “cause”, this question might be ridiculous. But if we think of the physical models as a general and powerful metaphoric formalism, this opens truly new ways of understanding and practicing artistic creation in the new technology context.

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