# Concepts and Technologies for Multisensory and Interactive Simulation of Physical Objects

## Application to Helios, a musical and visual artwork for the Helicanthe Platform of the ACROE

**Claude CADOZ**
ACROE – Grenoble – France
Claude.Cadoz@grenoble-inp.fr
http://www.acroe-ica.org/fr

### Abstract

*This presentation, in a first part, summarizes the genesis and the concepts that underlie the paradigm of "multisensory and interactive simulation of physical objects" introduced and developed by ACROE, as well as their implementation in a technology which is fully mature today, especially the Hélicanthe platform. In a second part, explanations are given on an artwork of the author, Helios, entirely realized with these technologies.*

## Introduction

The ACROE is a center for research and creation created in 1976 in Grenoble to carry out fundamental research and developments in the field of digital technologies for artistic creation, especially for sound, music and animated images.

The "*Multisensory and Interactive Simulation of Physical Objects*" is a qualifier, adopted by the ACROE to point out the concepts and the technologies whose development is at the heart of its program.

This program started with the *Digital Sound Synthesis* introduced by Max Mathews [Mat63][Mat69] in close collaboration with Jean-Claude Risset, who was the author's thesis director and who was also the President of ACROE until he leaves us in November 2016.

We introduced at this moment the first techniques for sound synthesis by physical modelling with the mass-interaction paradigm CORDIS that we invented in 1979 [Cad79]. We also developed at the same time a similar approach using the physical modelling to create animated images, through the ANIMA formalism [Luc85]. Then, we integrated CORDIS and ANIMA in a single and unified formalism, CORDIS-ANIMA, working as well for the sound, the animated image, as for the haptic or multisensory digital artefacts [Cad93].

From there, we developed a global and complete program concerning the general question of using digital technologies for artistic creation, in the fields of sound, music, animated image, multisensory and interactive arts.

The overall goal was to understand what fundamental changes following the advent of computer science could be expected and stimulated in this domain. Thus, from there, we began to define the basic functionalities of a general concept of "*tool for creation*" in the perspectives of digital technology.

This was an ambitious program, but we proceeded by defining steps that associated permanently theoretical works, technological elaboration, artistic validation in a permanent loop, each pole being stimulation and a support for the others.

This program has grown over 40 years, welcoming students from the Grenoble Institute of Technology, as well as other universities in France and abroad. More than 40 theses have been prepared and supported by the ACROE on this program. Many composers and artists have been welcomed and many artworks have been created with the tools and concepts that have been developed.

The ACROE is at the moment coordinator of a European network that is at the heart of digital technologies for artistic creation: the European Art-Science-Technology Network (EASTN).

I will report synthetically here this history, proceeding in two parts.

In the first part, I will present the main theoretical aspects and concepts that underlie the paradigm of "multisensory and interactive simulation of physical objects" as well as their implementation in a fully mature technology today, in particualr with the *Hélicanthe* platform.

In the second part, I will illustrate this with explanations about my piece *Hélios*, entirely made with the technologies we developed at ACROE and involved in *Hélicanthe*.

# I. Concepts and Technologies for Multisensory and interactive simulation of physical objects

Everyone knows well the double origin of the Computer Music, with Hiller and Issacson in 1956 for the Automatic Composition [Hil56], and Max Mathews in 1957 for the Digital Sound Synthesis [Mat63][Mat69]. The initial question for the computer music was "how to make music with a computer?". This question can be understood in many ways but there is one that is very radical: how to make music with a computer, and *exclusively* with a computer? In this case, we can say that it is necessary to start with the sound synthesis. So it is the attitude I adopted in this work, not because I consider that the other has no interest, on the contrary, but as a method I want to assume in full.

So, to start this presentation, I will focus on the sound synthesis and then I will try to show how what I call "*multisensory and interactive simulation of physical objects*" can be proposed in fact as a natural way to go to its generalization. It is not absurd to start things in this order, even if, historically, the "CAO" and the sound synthesis are born almost at the same time, because the first one can today apply just as well to the second. But I will not discuss this point in this presentation.

## 1. The digital synthesis of the sound

The question is now "how to make a sound with a computer?".

The sound in the real world always results from the vibrations of certain material objects composed of solid, fluid or gaseous components. The sound that participates in a musical situation can be simply perceived, no matter what makes it exist. It is enough, indeed, that the people who perceive it decide to consider it as possibly "musical", that it is pleasant or not, for all or for some only.

But let us limit ourselves to those that result from human action.

We can then say without risk, that to make sound, possibly musical, with a computer, it takes at least 2 first functional components:

- something that turns digital phenomena into acoustic phenomena - everyone knows that we have for that to add a DAC, amplifiers and Speakers.

- It is also necessary to provide interfaces where human actions can be carried out according to their different modalities. Leave aside for the moment the actions which involves the voice, so as to concentrate exclusively on those which are produced by the hands and the body.

Usually, it is the alphanumeric keyboard that responds almost exclusively to this function.

The next problem is what we have to place between these two borders, in what way and for what purpose?

An irreducible fact is the difference between the flow of information that we can produce by our physical actions, whatever the modality (writing, symbolic gesture, instrumental gesture ...), below some kHz, and the flow of information necessary for our hearing (a few tens of kHz). Let's call "R" the ratio between the output and input streams. The first task assigned to a sound synthesis program is then to produce (more or less) "R" times more output data than what it receives as input. The function is actually a function of "generation".

Music V, which carries the paradigm of the synthesis of sound created by Max Mathews in 1957 [Mat63][Mat69], responds to this first objective, even if, at the beginning it was no question of real time, with the Wavetable Scanning Oscillator. This fundamental component of the Music V formalism can produce an indefinite sequence from a finite number of given samples, and with slow rate variations of parameters.

A fundamental invention was added to the previous one, in Music V, which is the principle of the *functional blocks*. The output of a block can be used as input of a next block. Very quickly, with a coherent set of complementary and small numbers of functionnal blocks, it became possible to create an unlimited variety of sound synthesis processes.

Other approaches, which we do not need to recall here, developed on the same principle, in the 70s and 80s. But of all, a common problem emerged which gave rise to a discipline in itself: Psychoacoustics, linking Science and Technology on the one hand, and the Cognitive Sciences on the other.

Psychoacoustics is what allows, given a sound production process characterized according to structural specifications (a "patch" for example) and parametric data, to predict what it is necessary to do to obtain a predefined perceptive result, or, conversely, what will happen if one changes this or that (structural or parametric) specification.

Jean-Claude Risset was a pioneer in this field, developing his paradigm of Analysis by Synthesis; and you all know his work on sounds imitating the trumpet, the gongs, the bells, etc. as well as his famous paradoxical sounds [Ris82].

## 2. Paradigm shift

### 2.1. The sound object - ("*l'Objet Sonore*")

The work of Max Mathews, Jean-Claude Risset, John Chowning and many others that I cannot all mention here, gave the sound, through the principle of its computer reconstruction, the possibility of its "composition", as Jean-Claude Risset said to "*compose the sound*" [Ris89] [Ris14]). Sound has become itself an actual dimension of the Music; The Music known, by that, in the second half of the XXth century, a fundamental revolution.

This revolution follows the one that Pierre Schaeffer introduced in 1948 with the *Musique Concrète* [Sch66]. The sound recording technology had indeed solved a crucial question: the possibility of keeping an objective and (almost) absolute, indefinitely reproducible trace of the sound itself. Until the advent of the technologies of its recording, the sound phenomenon, fugitive by essence, and yet ultimate of the musical act, could enter into the duration only by indirect strategies such as the minetism (supposing also the preservation of the instrument), notation by tablature, and, of course, music notation on score.

But it must be observed - while sound recording allowed this absolute preservation of sound that traditional technologies could not accomplish - that notation, then composition in the sense of musical construction using musical writing, became very difficult only with recording.

With the Music V paradigm, it has been possible to enter in a new situation as illustrated by the publication of his “Sound Catalog” [Ris69], in 1969 by Jean-Claude Risset. This gave a way of an absolute preservation and possible re-construction of the sound thanks to the information embedded in the Music V “score”.

But in both cases, one can say that, indeed, the object of interest, the one that focuses all the attention and develops all the operations of representation, analysis, transformation and recreation is the sound. The one that Schaeffer had aptly named **“***l’Objet Sonore***”** [Sch66].

### 2.2. The physical object

Pierre Schaeffer considered that, for a deep understanding of the qualities of an *Objet Sonore*. allowing him to enter into a musical construction, it was necessary to completely abstract him from what could be its cause.

Paradoxically, one of the conclusions of the Psychoacoustics, in a context where the physical causes are precisely completely evacuated, like that of the digital synthesis, - where, as said Jean-Claude Risset, “[when one hears a sound of percussion made by a computer] *in the computer, nothing do not hit anything* " [Ris92] - the problem arises quite differently. In fact, we soon discover the strategies of the ear, which seeks, in a context where artifice dominates, to identify any trace that could bind to a possible physical cause of what is submitted to its perception.

At the beginning of the 90s, I introduced the theoretical point of view which bases the question of the relation between the properties of the sound such as our perception receives them and the causality of these [Cad91], thus joining the questioning by McAdams and Bregman [McA94].

It is therefore possible to pose the problem of sound creation in a totally different way, while preserving the principle of functional block construction, but applying it to the physical causes of sound rather than to the sound signal itself. This is the first aspect of the paradigm developed by the ACROE at the origin of its work.

I will introduce it now.

## 3. Interactive and multisensory simulation of physical objects

### 3.1. CORDIS-ANIMA

If we refer to the real situation, playing a musical instrument for example, but more generally each time that a physical action is applied to a material thing, there are always two combined categories of physical causes: the gesture and the material object on which it applies. Of course, the object must be special in the sense that it must be able to produce a sound as a result of our gestural actions. This is actually the primary function of any musical instrument. And our perception is capable in many cases (but not always) to distinguish what is due to the object and its properties, and what is due to the actions we apply to it.

This seemingly trivial circumstance is precisely that which lays the foundation for the paradigm of multisensory and interactive simulation of physical objects.

It would be tempting to treat the gesture and the object on which it applies as two separable entities. But the gestures we apply to a physical object depend on its physical properties and, inseparably, our own physical properties - which are complex and, moreover, variable in the course of our action. This leads us to consider the interaction itself inseparably from what is interacting.

The dualism of physical interactions results in the fact that two related variables are needed to describe them, and that's what introduces a break with the paradigm of the input-output functional blocks of Music V (and its derivatives).

In CORDIS-ANIMA [Cad93], which is a formalism to model and simulate the physical objects and their interactions, the exchanges between the modules are then by principle double. They always associate, at the same point of communication, an input bearing a position and an output carrying a force or vice versa. And the basic formalism encapsulates this by implementing two categories of modules, called respectively "material" and "links", <MAT> and <LIA> in the CORDIS-ANIMA language (Fig. 1).

With the CORDIS-ANIMA formalism, as a consequence of these premises, a model is not of the form of an oriented diagram, but of a network where the nodes and the links are, respectively, <MAT> and <LIA> elements.

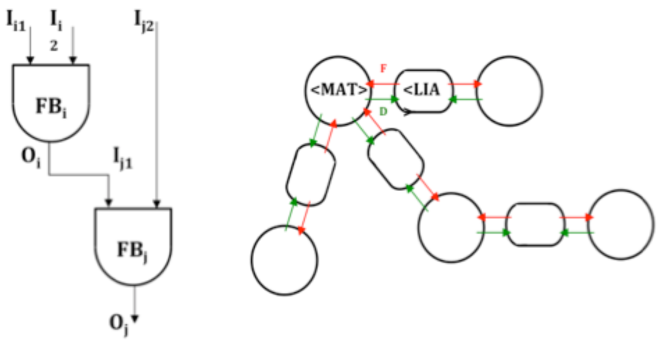


**Figure 1.**
a) Flow oriented block diagram (Music V)
b) Bidirectional paired input / output (CORDIS-ANIMA)

The basic algorithms of the CORDIS-ANIMA formalism for the <MAT> category (MAS and CEL), on one hand, and of <LIA> type (RES, FRO and REF) in the other, do not result from arbitrary choices or decisions. They are the result of an absolute algorithmic optimization, at the level of the elementary digital operators and memory resources. They thus constitute a kind of axiomatic system.

The sound synthesis by physical model is then one of the facets of this approach. Indeed, the principle stated above has the natural consequence that the same algorithms, without adding anything, makes it possible to produce also movements for animated images as well as the forces for the systems used as gestural interfaces, in particular the force-feedback devices. Note in addition that the CORDIS-ANIMA allows, even if sometimes it will be with less algorithmic efficiency, to emulate all the functions of the modules of the signal modelling and signal processing methods.

The CORDIS-ANIMA paradigm, created as a formalism for "modelling and simulating instrumental physical objects" [Cad79] has not explicitly been introduced as a system for "physical modelling". The term did not exist yet, in any case in the field of computer music. It was not until the beginning of the 1980s that an explicit distinction was made between two categories of methods of synthesis, known as "signal modelling" methods (which corresponds to Music V and all its descendants or derivatives) and "physical modelling" methods.

And indeed, several approaches related to the second, have developed in a close period. Let's mention the "Modal Synthesis", with Modalys [Adr91], Waveguide Synthesis [Kar83][Jaf83]. Let's also mention works, among a lot of others, on plucked-strings and wind instruments like those of P. Cook [Coo92][ Coo97] and various approaches based on the mathematical modelling of vibratory phenomena in physical structures. The latter have generally the aim, using synthesis, to better understand the physic of real musical instruments, in order to perfect them [Gui03].

### 3.2. Force Feedback Gestural devices

A force feedback system is nothing more than a <MAT> (or <LIA>) module that produces a position (or force) signal in response to the force (or position) we impose on it. However, there is a difference: it does not realize this relation through the numerical simulation of a physical object, but ... with a physical object. Of course, this one is not quite in its natural state, because it is equipped with two technological components:

- One to convert its current physical position (or the force it receives from our gesture) into a digital signal which represents it and which then serves as input to the module of type <LIA> (respectively <MAT>) to which it is connected in the model; A sensor.
- The other to convert the signal of force (or position) produced by this same part of the model, into a force (or position) applied to our hand (or our fingers); An effector (a motor).

Let's say that such a device, which inherently combines the two, is a "Retroactive Gestural Transducer", a RGT (TGR in French) [Cad88]. In general, we say a "haptic system".

But an important part of this system is the "kinematic converter", which is the mechanical part that puts under the fingers the axes of the motors and sensors according to several degrees of freedom, with different trajectories and shapes depending on the application.

All these concepts and systems have been already presented in numerous occasions [Cad88][Cad90][Flo04][IDM08][Leo4].

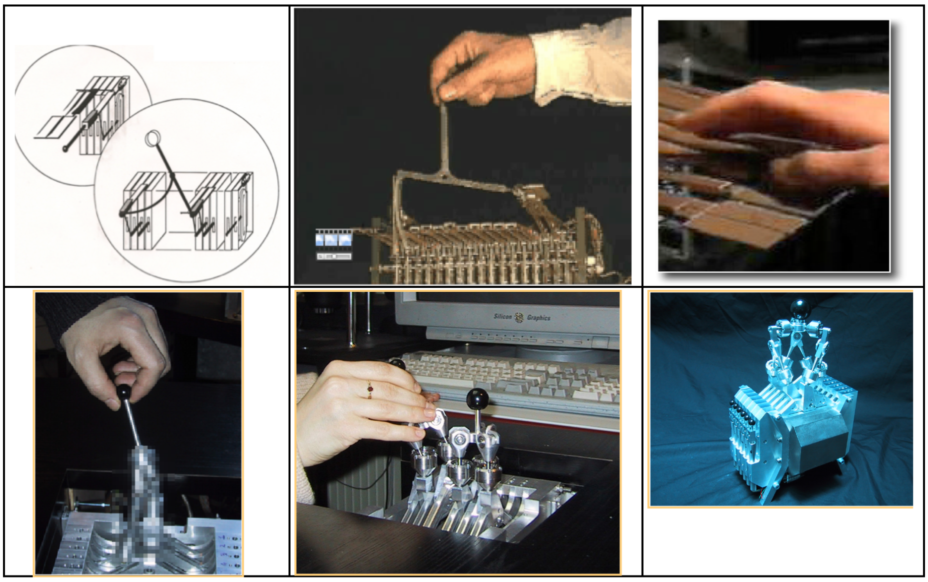

**Figure 2.**
Force-feedback devices from ACROE
Slice motor end-effector modularity and morphologies
1988 - 2014

In fact, the domain of the force-feedback (haptic) devices is quite wide. The first haptic arm was developed for molecular simulation in the GROPE Project [Brooks, University of Chapel Hill, 1971]. It uses the first famous electrical teleoperators from Argone Labs [R.Goertz 1954], or from CEA-France [MA23 project, Vertut 1976]. From them, lot of new devices have been developed more recently, such as the 6D Virtuose device commercialized by *Haption* (France) or the devices commercialized by *SensAble* (USA) [Sen].

Several different family were developed, with different principles: those that mime the human arm morphology, mainly for robotics tele-operation (Fig. 3), those, more generic, adopting mechanical principles, called « parallel mechanical transmittors » which allow to adapt more flexible end-effectors (i.e. the part of the device put in hand), as in the first famous device published by James D. Foley [Fol87], which inspired lot of haptics devices (such as the Spidar systems [Ish94], or the 6D Delta device marketed by Force Dimension [For], or also the very cheap Novint device.

We can also mention the family of "exosquelttons" like the Fuchs (France) [Ras98], force-feedback glove, the PERCRO (Italy) exoskeleton, or the Immersion (USA) *Immersive* force feedback system (Fig. 3).

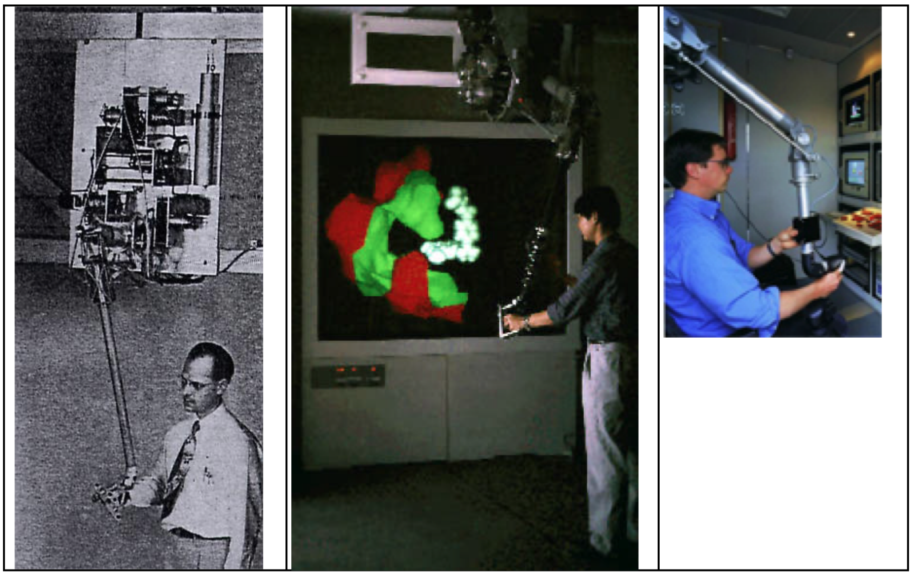

**Figure 3.** First Force-feedback devices
Argone labs - R.Goertz 1954 - Electric tele-operators
GROPE Project - Brooks 1971 - Chapel Hill University
CEA - MA23 project - Vertut 1976

Note, to conclude this chapter, that force-feedback is not always necessary in instrumental gestural interactions. We have drawn in the past a "typology" of the instrumental gesture [Cad94][Cad99][Cad00] which puts it well in evidence, and which allows to determine when it is actually necessary in gestural interfaces if we want to emphasize the richness of the gesture and the crucial role it plays in the expressiveness of the sound. When it is not necessary, of course, the technology is simpler.

Many experiments carried out in our lab with our systems as well as with many others [Flo02][Gil94][Gio10][Nic00][Sin11] confirm these analyzes.

### 3.3. Interactive and multisensory simulation of physical objects

As we already said, the simulation of physical objects using the CORDIS-ANIMA mass-interaction formalism, find direct application in the sound synthesis. The combination with the Retroactive Gestural Transduction (TGR) allows to extend this remark, but, as we noticed also, there is no necessity to add any other technical functionality to address movements of visible objects or forces for haptic devices; so thanks to these two technical components, we are able to achieve what can be named "*interactive and multisensory simulation of physical objects*"; that is to say, a simulation of physical objects in such a way that we can interact physically (by our gestures) with their simulacra and perceive them, during this interaction, by the hearing, the vision and the haptic sense.

## 4. ERGON, GENESIS, MIMESIS, TELLURIS and *Hélicante*, the platform for multi-sensori-motor creation and multichannel audio and visual projection

CORDIS-ANIMA is associated with a language, the Physical Network Simulation Language (PNSL) developed by ACROE [Luc06]. It is used to load a "Simulator" that performs a fully optimized simulation protocol according to the CORDIS-ANIMA specifications.

• ***Real-Time / Deffered-Time***

The computation time needed by the simulation is directly dependant of the complexity of the model, that is to say the number of modules it contains. A critical point here is then whether this complexity allows or not that the complete computation loop, including input data acquisition and output data delivery, can be performed during the sampling period. This determinate the possibility that the simulation can be done in real-time or not.

Today, using quite standard computers, it is possible to access to the real-time for about 6 to 8 thousands of components.

If we accept to process in two phases: i) the design of the model, followed by ii) its simulation in deferred time (finalized by the listening once the computation achieved), there is not so strict limitation. For example, we simulated recently structures containing until 300,000 components.

The main question here is obviously of a new nature: independently of real or deffered time, how to handle such huge amount of specifications? with which practical tool? and according to which method?

### 4.1 GENESIS

GENESIS [Cas02], the user interface for CORDIS-ANIMA physical modelling responds to the first point for the case of musical creation. It has been presented on numerous occasions since its first version (inaugurated for workshops and musical projects at the ZKM centre in Karlsruhe in 1996). It is always in evolution, being a central activity of ACROE lab.

We now have a very powerful and comprehensive tool, used for intensive research projects and artistic creations. I will give more details and some examples in the second part of my presentation dedicated to my audiovisual artwork *Hélios*. I will show what kind of method can be implemented and how the physical metaphor can also be used in a totally surreal way, with incredible and absolutely scandalous transgressions of the official reality.

For now I'm just going to remind you about its appearance, basic features and some ergonomics features with a small example showing how to build a string.

The GENESIS user interface makes it possible to build models according to CORDIS-ANIMA formalism by arranging their components on a workbench. The components are basic algorithms according to the two categories <MAT> and <LIA>, corresponding to punctual masses (MAS), elastic interactions (RES) viscous interactions (FRO) as well as some elementary and optimized combinations of these (Fig. 4).

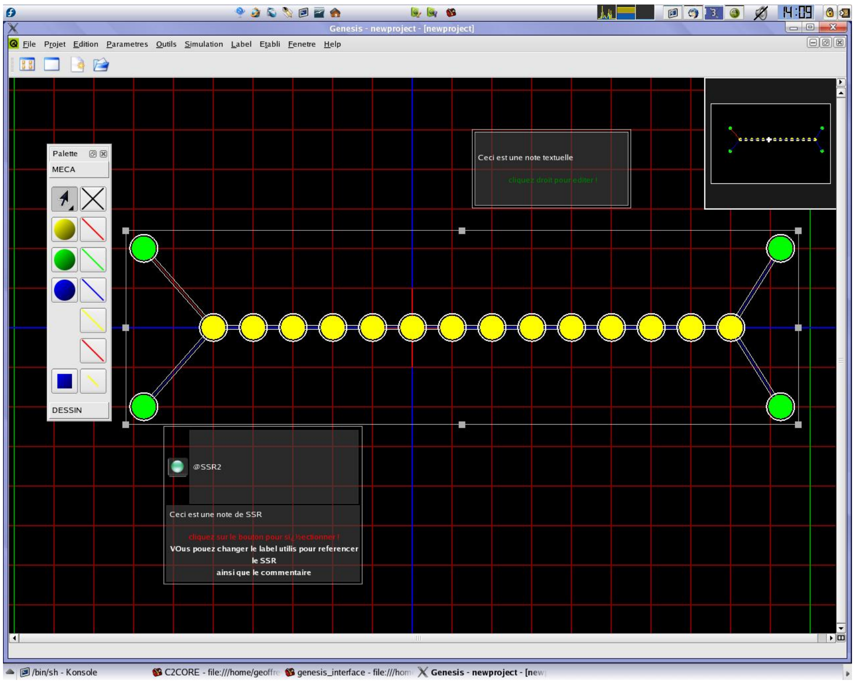


**Figure 4**.a - GENESIS workbench - Simple example - a Vibrating String

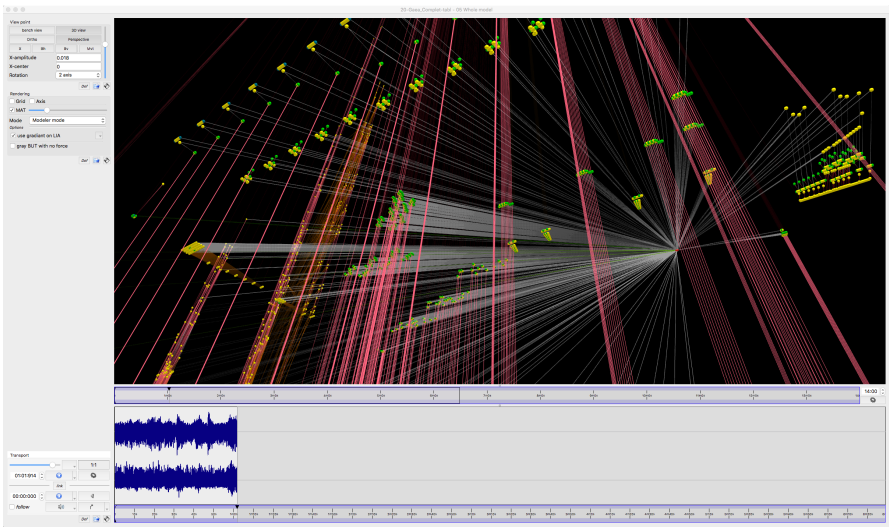

**Figure 4**.b - GENESIS Simulation window – « *Gaea* » - Cadoz 2007, 2015

## 4.2. MIMESIS

MIMESIS is the user interface for CORDIS-ANIMA physical modelling responding also to the first point of the previous question for the creation of animated images. It has been developed by Annie Luciani and her team in ACROE and also presented on numerous occasions. [Evr06].

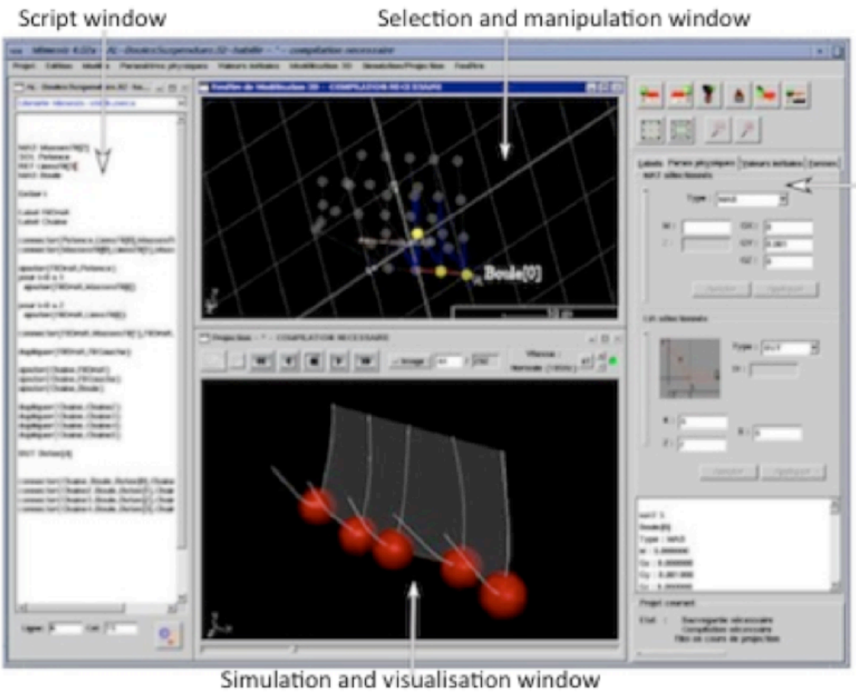


**Figure 5.** The MIMESIS modelling Bench

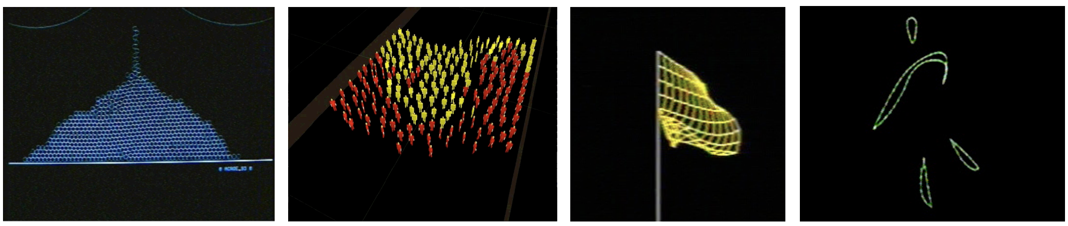

**Figure 6.** The MIMESIS modelling BenchPhysical CORDIS-ANIMA and MIMESIS models for computer animation : Sand, Crowd, deformable objects, Puppet. From A. Luciani

### 4.3. TELLURIS

Let's take a closer look at the technical features and functionalities that need to be implemented in a complete platform for multisensory interactive creation.

- ***Real-Time simulation for the Gestural Channel – The* ERGON *base***

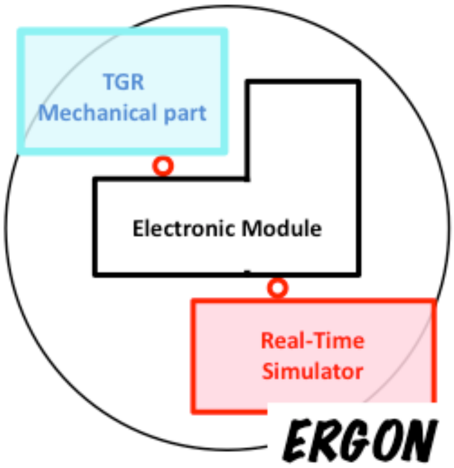


**Figure 7** – *ERGON* TGR base

A TGR consists of a (real and tangible) mechanical device supplemented, as mentioned above, by a sensor (for example a position sensor) and an effector (for example an electromagnetic motor).

Then we have, as for the audio channels, the converters as well as the electronic conditioners.

Note simply that for each degree of mechanical freedom, there must be an "electronique function" composed both of a conditioner-CAD chain and of a DAC-amplifier chain.

Then, the digital signals to and from the electronic modules (the "communication signals") can be respectively the input and output signals of the simulator, which is,then, necessarily a real-time simulator.

As for the simulation, it must at least acquire the digital signals produced by the electronic module, and provide input signals of the power amplifier (included in the electronic module) which supplies the motor of the TGR.

We call "*ERGON*" this set of three coordinated functionalities.

The simulation algorithm can be reduced to its simplest expression, whatever the principle used, in relation or not with the CORDIS-ANIMA formalism.

Note, at this stage, that what we call above the "*communication signals*" are directly available for any external applications. Note also that the simulator itself can be omitted, that the electronic module can be constituted of only a conditioner or only an amplifier. In both cases, we can of course no longer speak of TGR, but of simple TG, or simple motor; which may continue to get meaning and uses. This shows in fact that the concept and technology of *ERGON* are inclusive and modular. It is up to the user to adapt it to his application.

But the simulation program can also be very sophisticated, solely limited by the power of the computer we have at our disposal.

The global framework for the Real-Time Simulator is easy to characterize: to produce from direct or recorded input, any kind of output to be recorded for a further use, or directly send to gestural, audio or visual interfaces, individually, separately or in a "multisensory" combination.

Then we can propose the following functional diagram, including storage devices, "multi-sensori-motor" display and digital communication network streaming (Fig. 8).

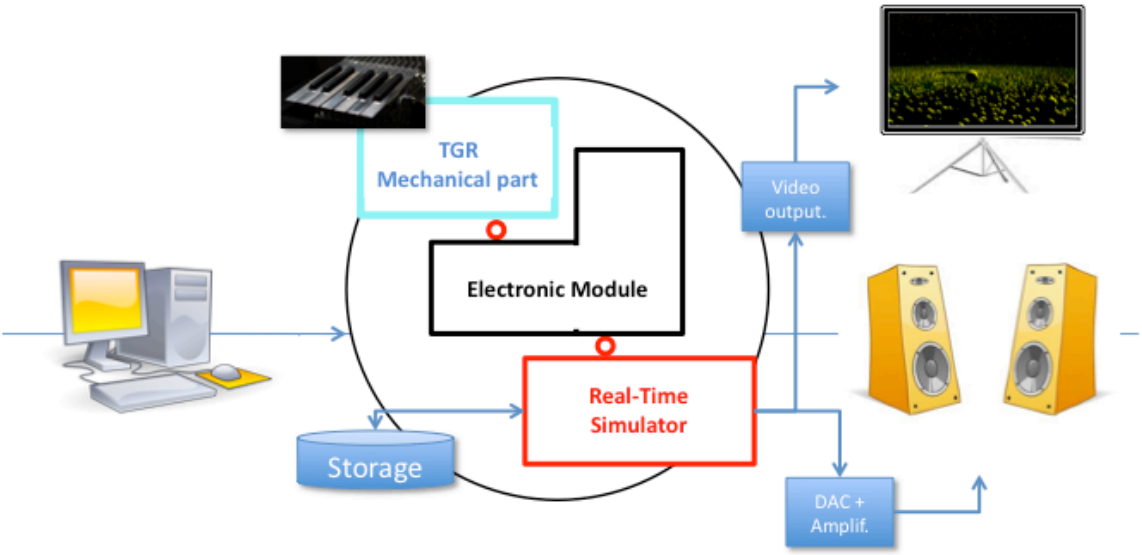


**Figure 8** – Global framework for the Real-Time Multisensory and Interactive Simulation

- ***Multifrequency Real-Time simulation for the Gestural Channel***

Let's place here a remark echoing the one we made in the 1st chapter, which is that there is a ratio "R", between the flow of information that is necessary for our hearing and the one that we can produce by our gestures. In the context of real-time simulation, we introduced a new way to optimize the calculation: the *multi-frequency simulation technique*, which takes support on this fact.

For this, we may separate the model into several parts that will be simulated at different rates, adapted to the bandwidth of their physical behaviours. For example, this division can be in two parts, one simulated at a low sampling rate, corresponding to the bandwidth of the gestural phenomena, the other at a high sampling rate corresponding to the audio phenomena.

Technically, this raises two questions: i) how to determine the frontier between low and high parts, ii) How to make correct correspondences between the low frequency digital signal and the high ones, given that the two categories of physical variables - the forces and the displacements - must be treated on two different ways?

We solved this at the ACROE, with the works of James Leonard, Nicolas Castagné, Claude Cadoz and Annie Luciani as part of James Leonard's thesis, [Leo18]. The results are quite satisfactory, allowing increasing significantly the complexity of models that can be simulated in real-time.

• ***The* TELLURIS *platform***

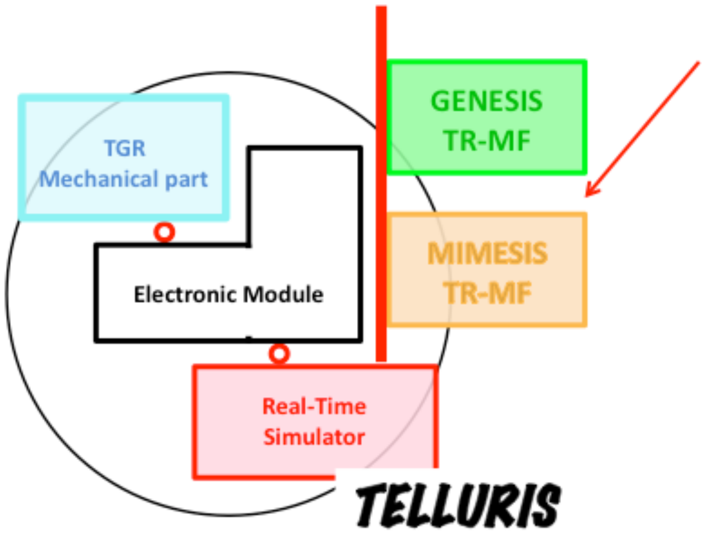


**Figure 9** – The TELLURIS platform

The CORDIS-ANIMA formalism (precisely because it has been specifically designed for this) is particularly suited to the design of simulation programs that meet these needs in terms of paired inputs and outputs, computational optimality (especially by multi-frequency simulation) and modularity.

This brings us to consider the combination of ERGON technology, on the one hand, and modelling interfaces - GENESIS for sound, and MIMESIS for moving image - on the other, as constituting a coherent and comprehensive tool for the sound and music, the visual, the multisensory and interactive creation. This is what we call the *TELLURIS platform*.

### 4.4. *Hélicanthe*

Any <MAT> module moving, as well as any <LIA> bearing an interaction force during the simulation of a CORDIS-ANIMA network can be used for output. Two complementary dedicated modules, respectively of <LIA> and of <MAT> type play this role. The first, called "SOX", connected to a <MAT> gives a displacement signal; The second, called "SOF", gives a force signal, both being ready in a digital audio format for recording or for output on an audio channel.

• ***Sound spatialization - Sound Dome***

In fact, any <MAT> or <LIA> element in a simulation can feed an audio channel, so that there is no other limit for the number of outputs than the actual audio channels we have at our disposal, and, for the real-time situations, the power of the computer.
In fact, any <MAT> or <LIA> element in a simulation can feed an audio channel, so that there is no other limit for the number of outputs than the actual audio channels we have at our disposal, and, for the real-time situations, the power of the computer.

The *Hélicanthe* platform uses, for audio display, a multichannel system, a "Sound Dome", according to the technology developed by Ramakrishnan, Gossmann, and Brümmer, in the ZKM centre of Karlsruhe (Germany) [Ram06].

I will only give an example of use of CORDIS-ANIMA for sound spatialization, in this technical context. Within *Hélios* again, the sources of the audio outputs can be points distributed at the surface of a "big gong" and connected to the 24 loudspeakers of the Sound Dome. Doing that, you can listen the scene as if you were a Lilliputian under the Gong placed horizontally (or as if you were a normal human, with a huge Gong above you head), hearing then the impact positions at the various places on the vault.

A similar approach can be developed for the visual outputs, but it would be necessary to enter in more details to understand what is specific to each case.

What we call the *Hélicanthe* platform, then, corresponds to the assemblage of these functionalities, going from the very core of this "*supra-instrumental*" [Cad09] situation, with the force feedback devices, to the multi-spatial audio and video projection.

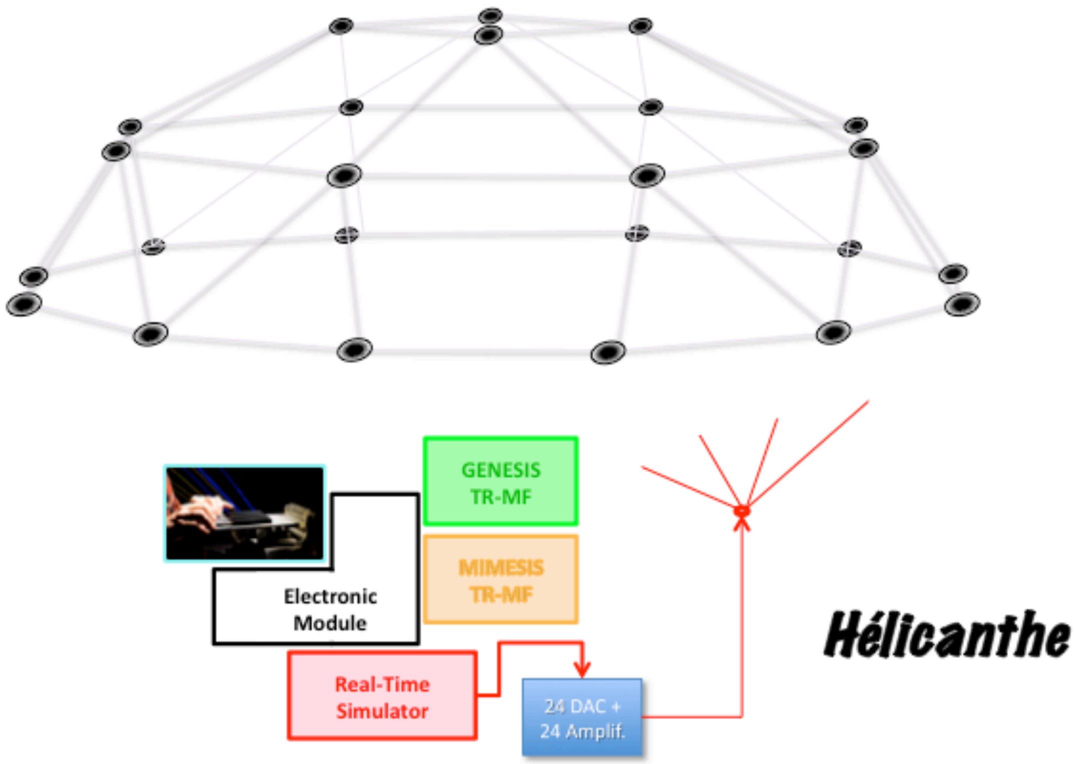


**Figure 10** – *Hélicanthe*

- ***The Interactive Multisensory AGORA***

Let's finish this chapter with yet a name.

Of course, it is possible to put together several installations in the same place, with several computers connected to the same outputs audio and visual devices, and also with several TGR, dispatched in the room. More, it is possible to place it in a "hyper communication network" (Internet) comprising several interconnected platforms of this nature.

It is very interesting to consider this, but it is even more interesting to notice what are the real, unsurpassable limits of the “Electromagnetic Hyper-Communication Network”.

All the experiments made by researchers who have worked on instrumental interaction show that actions and gestural perceptions in our interactions with the real physical world, to be restored with all the finesse of which we are capable, must be taken into account with bandwidths of several kHz.

Below these conditions, the material world under our fingers is poor and sad.

This is one of the reasons why, in order to bring its full interest, the technologies of the force feedback systems must be approached with a high performance requirement.

If now we put all this in a context of communication and interaction by electromagnetic waves, then, recalling that they move at best at the speed of light, it follows that an "instrumental" type contact - that is, in the bandwidth conditions necessary for the interaction with force feedback - can be established remotely. But the maximum distance cannot exceed a few hundred kilometers.

Consequently, it appears that a truly instrumental interaction is definitely impossible on the Internet and that it is better to immediately abandon such utopia.

On the other hand, it is important today to focus, in complementarity with "the electromagnetic hyper-communication networks", to enrich the local platforms with all that constitutes the multisensory and interactive environment as we have defined it.

This does not prevent, on the contrary, to plunge such environments in interconnected networks, but without forgetting that what corresponds to the fine expressive gestural purposes cannot be transmitted.

This gives its total legitimacy and necessity to the "real life" in the “real world”, which is not exclusive to "connected life".

Let’s call that the *Interactive Multisensory AGORA.*

## II. *Hélios* in *Hélicanthe*

*Hélicanthe* is now like a toy universe in which we can discover strange and poetic regions. Some years ago, I discover a kind of planet, I thought it was a memory of the Earth, but I was not sure. However I called him *Gaea*. I sat there and watched for a long time, from beginning to end of the light. Perhaps it was a reminiscence of the ancient Sun. I called that moment *Hélios*.

*Hélios* is a multisensory artwork entirely created within the *Hélicanthe* platform. It was presented publicly for the first time in Grenoble, in November 2015, as part of the closing concert of the European project EASTN (European Art Science and Technology Network) (#AST2015). The architecture of the *Hélicanthe* platform used for the design of this artwork as well as for its first public presentation was as described above, with a 8 DOF[1] TELLURIS station, a Sound Dome with 24 loudspeakers distributed on an hemisphere of 10m of diameter, and two large screens, one for the large scale visual scene, the other, semi-transparent, placed in front of the ERGON station and its performer, to display the visual scene of the real-time simulation made with TELLURIS. The complete work is made of two big CORDIS-ANIMA models, both created with GENESIS. One is for the live part to be played with ERGON. It comprises about 8,000 modules (Fig. 11b), and the other for the master scene, calculated in deferred time, comprises 120,000 modules (Fig. 11a).

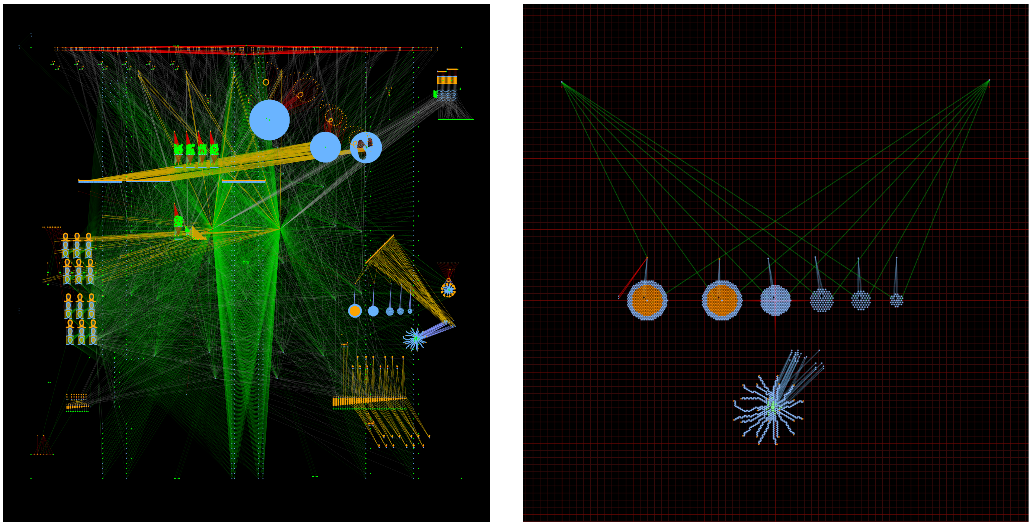

**Figure 11** – Hélios – a) Deffered-time part (120,000 modules) b) Real-time part (8,000 modules)

**Figure 12** - The ACROE-TGR in *Hélios* –

[1] DOF: Degrees of freedom

The time-deferred part is pre-calculated. All the sounds are recorded in the suitable number of audio channels, and all the movements of all the particles are recorded in a 3D virtual space in which we can navigate while the particles are moving in it, during the final displaying, in synchronism with the live and real-time performance.

The main scene is made up of about 40 independent "instruments", i.e. sets of modules each producing sounds with their own characters and that do not interact with each other.
You can notice that the instrument in the real-time part (Fig.11 above) is also present in the master. This is done to allow a duet between the pre-calculated part in the master and the live part played in real time.

I will describe now some subparts of this work, illustrating some of the original techniques allowed by the CORDIS-ANIMA paradigm, as well for the creation of the sound as for the musical macro-temporal structuring.

## 1. Vibrating Supra-structures

### 1.1. Gongs

***• Big Gong***

In *Hélios* there is a very big gong made of about 20,000 modules arranged on a circular plate according a triangular meshroom topology (Fig. 13).
To stimulate its vibrations, it suffices to project a particle, at a given speed, towards one of the points of its surface. The intensity of the vibrations will depend directly on the speed with which the particle has been launched. And the various vibrating modes characterizing the plate (according to its shape and to the parameters of its components) will depend on the place of the impact in the surface.

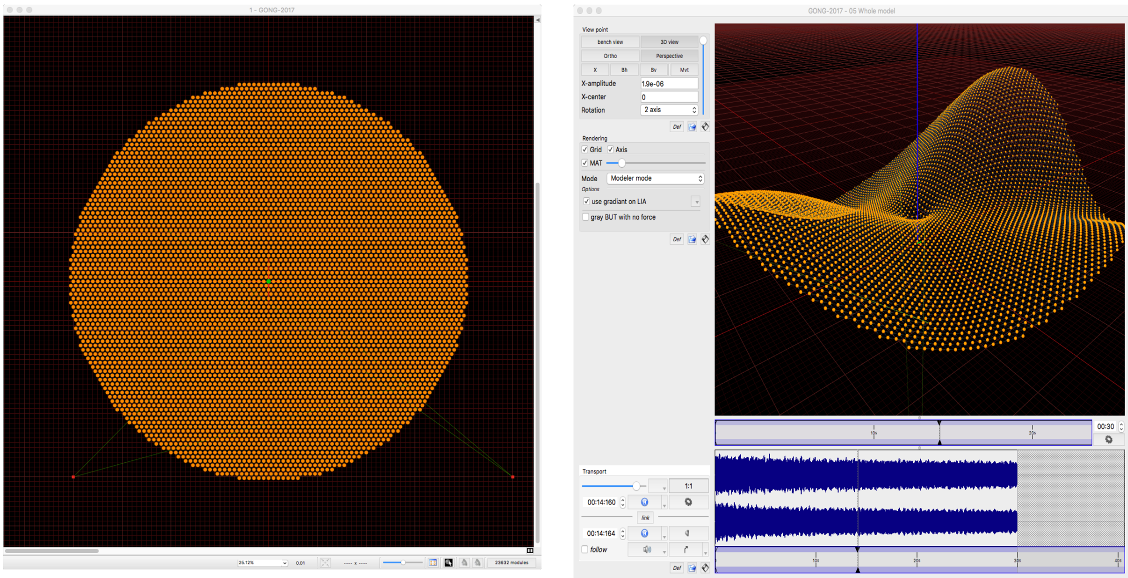

**Figure 13** - a) Big Gong in *Hélios* (23,632 modules), b) Modal shape of Big Gong in *Hélios*

- ***Torn gong***

We can see it in the upper right corner of the scene (page 17). Some parts were removed, as if they had been devoured by mites. This strange process, difficult to obtain in the real world (because mites do not usually eat metal), leads to amazing results: A lot of the modal components of the initial Gong are preserved, but some are modified in there spectral placement, giving an interesting modulation, particularly attracting when we play with the fine relative temporal occurrence of these cousin Gong.

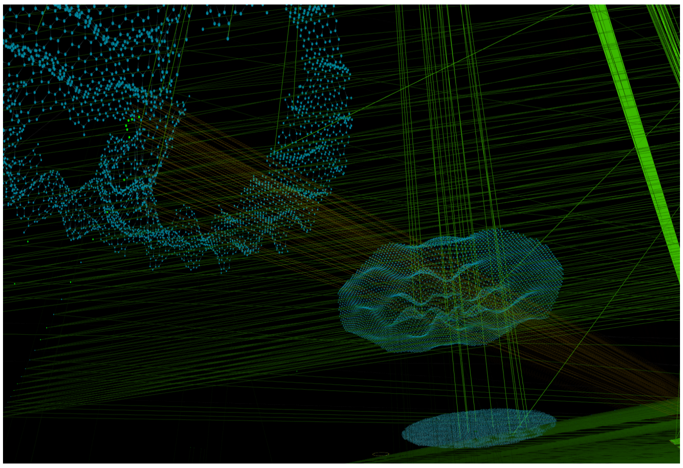

**Figure 14** – « Cousin » gongs – integrated and eaten by the mites

- ***Gong burst (Fig.15a)***

Continuing this disintegrative approach, we can also break the Gong into several pieces. Its fundamental integrity (as well as its fundamental vibratory mode) is then broken. But there are still some relations, due in particular to the most acute modes, found in the small pieces.

- ***Gong powder (Fig.15b)***

Let's continue this metaphor to its ultimate limit, where the gong is decomposed into its smallest parts: the elementary vibrating particles (they correspond, in GENESIS, to what are called cells, which carry a single vibratory mode).

It must be confessed here that for this last stage of decomposition, the method is no longer "metaphorical" since it consists in performing a complete modal analysis of the initial Gong (an operation that can be very easily performed with GENESIS), and then creating as many of cells that there are modes and, finally, to tune all these cells to the frequencies resulting from the analysis. The frequency tuning of a structure is indeed an operation as easy to do in GENESIS, as its analysis (provided that it is linear). I would like to humbly dedidate to Jean-Claude Risset these processes that are symetrical, and transposed in the physical modelling context, of the mutation from the melodic to harmonic assembly of frequencies in his piece “Mutation” (1969).

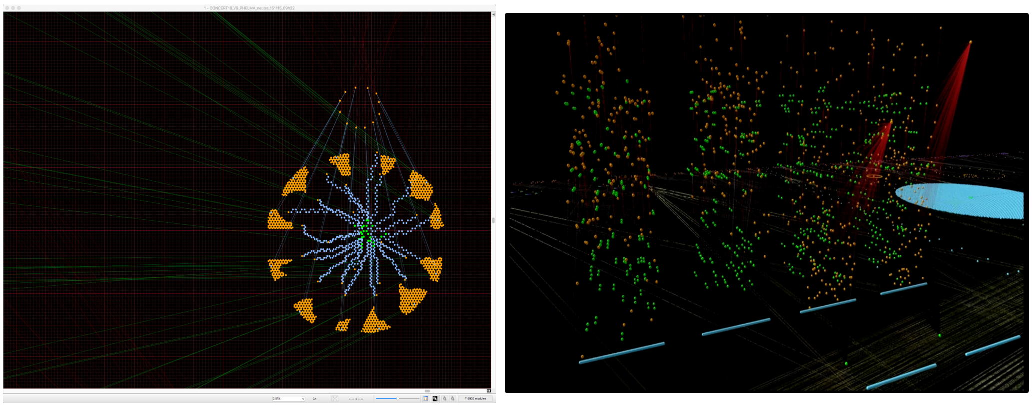

**Figure 15** – a) Gong burst – b) Gong powder

- ***Riemann gong (Fig.16)***

Let's go now in the opposite direction.

The “Gong of Riemann”, named after this famous mathematician, is no longer produced by decomposition, but by over-composition.

Two gongs such as the previous, are superimposed. Both are split along a radius and then one of the resulting edges of this slot on the first is "sewn" with the opposite edge on the other gong. Conversely, the two edges left free, are sewn in their turn.

The acoustic properties of this impossible object (also reminiscent of the Moebius band) are astonishing because they both retain those of the original gong and introduce a doubling of these to an octave below, giving a kind of "thickness" to the sound.

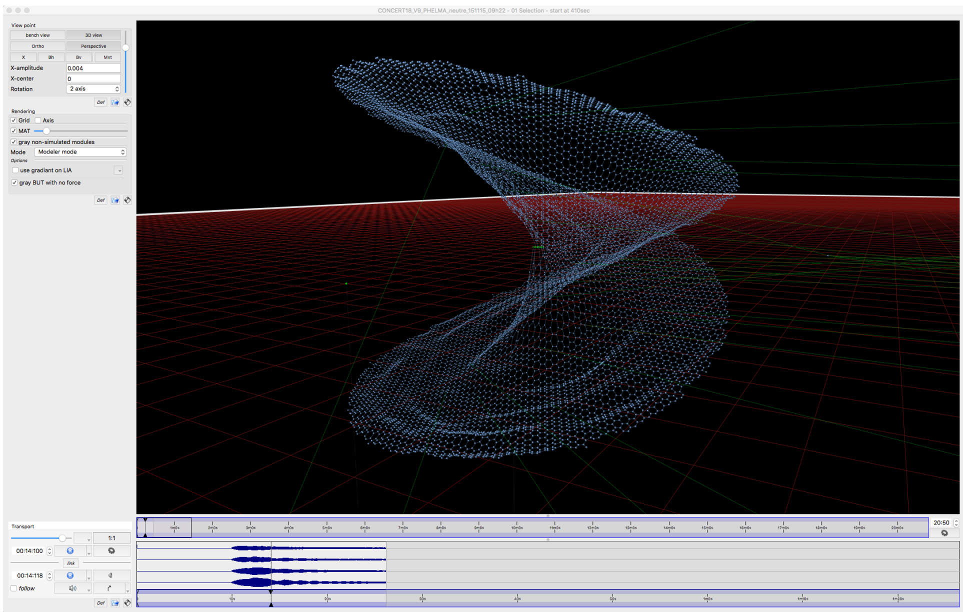


**Figure 16** – *Very low Fundamental mode of the Riemann Gong -*

### 1.3. Resonances

As for the "resonances", by the way, each of these objects can be played by vibrating them with a simple percussion using a particle trapped in a cavity, launched at an initial speed such that it makes quick trips back and forth between the limits of the cavity. This particle adopts a "triangular" movement, spectrally rich. By changing the size of the cavity, the frequency of this triangular oscillation is changed.

Helios implements such processes, applied to objects that have rich modal properties, such as those we have just seen. The resonances of these objects emerge and disappear, or combine in a rich way.

## 2. Supra-Gestural structures

We call “supra-gestural structures” CORDIS-ANIMA structures with dynamic low frequency properties; more precisely whose frequencies are lower than the acoustic frequencies, and which may in particular have continuous motion components.

Such movements are of the same nature as our gestures.

The idea then comes to consider CORDIS-ANIMA as a means of modelling ... the instrumentalist himself (in all modesty and, not to offend the instrumentalists, really without to pretend replace them with models, even built with CORDIS-ANIMA).

In order to completely reassure the instrumentalists, but also to show a new field of possibilities, there are here after two simple examples (there could be many others).

### 1.3. Cosmic Snakes

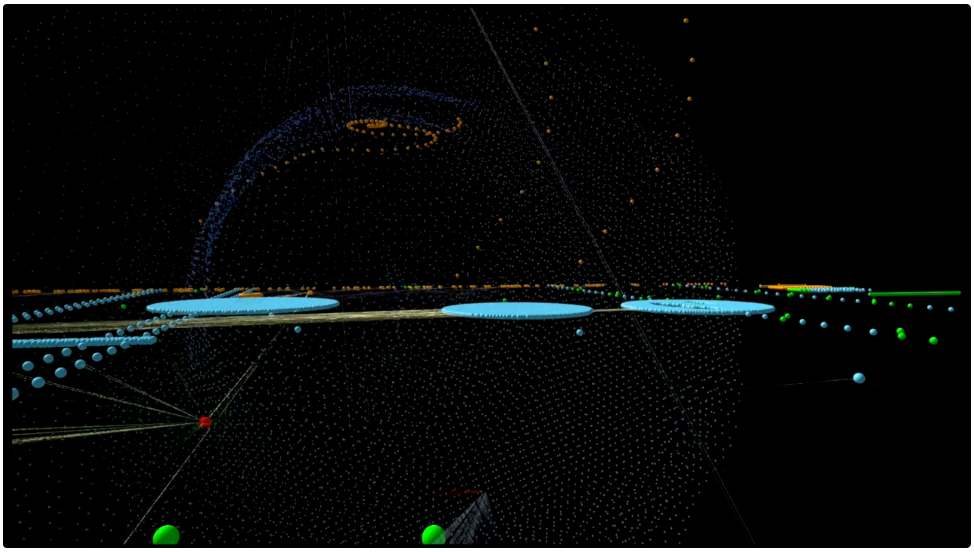

**Figure 17** – *Cosmic Snakes*

They are simple sets of particles, like the ones we mentioned before to strike the gongs, but which have altitudes according to a precise law, taking the precaution that they all have the same initial velocity.

By this means, it is very easily and very explicitly generated percussive events, for example at regular intervals, if these particles have been placed on a regular altitude scale.

But we can also make sure that these particles impact a normal vibrating structure, for example the previous gongs, at certain points, also judiciously chosen.

Everything happens then as if we made a gesture following this form, on our instrument

### 1.7. Stratospheric Waves

Let's go down a little, at the level of the stratosphere (it's just for the poetry of the name) and build a structure in the form of a chain of masses connected by elements of visco-elastic interaction.

Built with normal parameters, it produces sounds that easily evoke those of a string.

But with parameters conferring vibratory modes of low frequency, it will behave like a slow wave.

It is not certain that one can find such an equivalent in reality, at least on our immediate scale.

However, having constructed such an object, one can attach to each of its material components a device like a plectrum or a small percussion stick and make this huge string, slowly propagating its wave, comes to play on all the series of "instruments" that we present to his action.

This is done in the very last sequence of Helios, where such a wave plays a melody emerging from the series of instruments arranged under its reach.

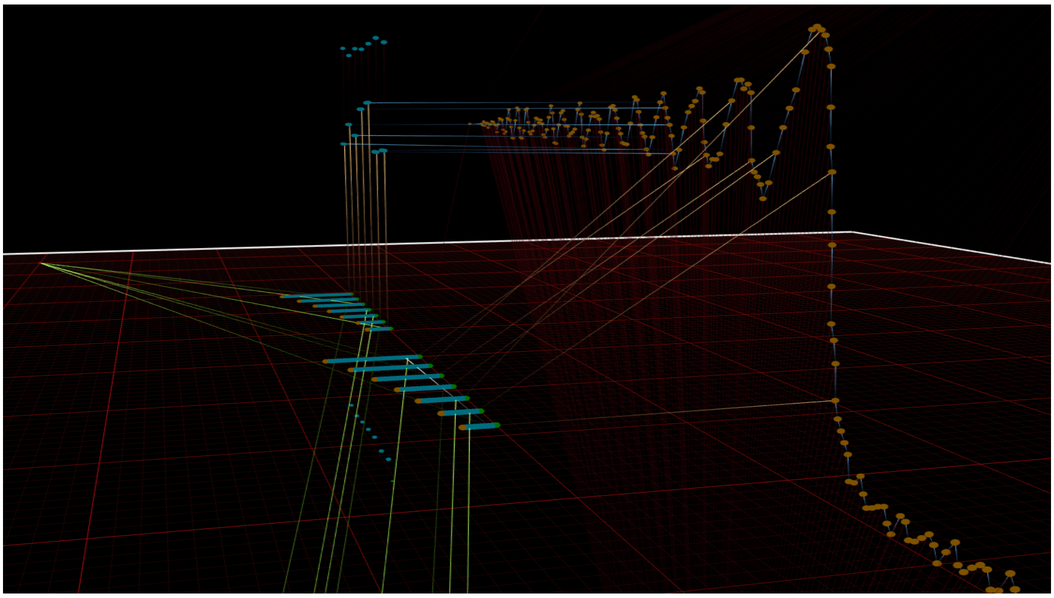

**Figure 18** – *Stratospheric Waves*

As a conclusion, all that remains is to listen to this piece.

The best is during a concert, but it is possible to ask the author for a video extract.

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## Aknowledgements

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