



**HAL**  
open science

# Modeling methods for sound synthesis. Network combinations and complex models for physical modeling: application to modes clustering

Eric Incerti

► **To cite this version:**

Eric Incerti. Modeling methods for sound synthesis. Network combinations and complex models for physical modeling: application to modes clustering. ICMC 1997, Sep 1997, Thessalonique, Greece. non paginé. hal-00481804

**HAL Id: hal-00481804**

**<https://hal.science/hal-00481804>**

Submitted on 7 May 2010

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Modeling Methods for Sound Synthesis. Network Combinations and Complex Models for Physical Modeling: Application to Modes Clustering

Eric INCERTI<sup>(†)</sup>

*eric@sound.music.mcgill.ca*

A.C.R.O.E. - C.L.I.P.S.

I.N.P.G. - Institut IMAG

46 Av. Felix Viallet 38031 Grenoble - France

## 0. Abstract

In the field of sound synthesis with physical modeling, particle networks represent the simplest way to model complex vibrating structures. To reach a more accurate knowledge of these structures and their properties for a better control of the simulation processes, we have been driven to focus upon some special classes of networks and to study carefully the modeling methods and the underlying theoretical and algorithmic conditions. Several interesting properties appeared concerning parameters, quantizations effects (matter and time) and construction rules. These properties give access to numerous suitable models to perform a great variety of simulations under a complete control (acoustic, algorithmic and mechanical).

## 1. Introduction

If the general principles of physical modeling (PM) are known for a long time (J. Bernoulli wrote the first physical model of a vibrating string in the 1860's) the use of PM in the field of sound synthesis is quite recent - less than 30 years. For a decade, computers being faster and faster, PM has been pushed into the forefront in many scientific areas and now appears to be the most promising technique for sound synthesis.

The main reason is surely that PM offers a convenient and convincing vision of sound synthesis for both scientist and musician [Roads,94]. The principles are simple, rigorous (based on simple mathematical models of acoustics instead of DSP gizmos) and the simulations produce very rich and realistic sounds (and it is the same in other fields of PM application such as animated images, robotics...) But to make the most of these new techniques, a great attention must be paid to the modeling methods.

In this paper we focus upon the study of the vibrating structure [Incerti.95] as a "mass-spring" network and we present some modeling methods and network combinations that enable to build complex objects with a complete control on the acoustical and mechanical parameters. This study is carried out under some specific algorithmic condition (the CORDIS-ANIMA formalism

[Cadoz.93]) but deals with general problems in computer modeling.

Finally, an application of these modeling methods and network combinations is presented. It enables to thicken a vibrating structure by "clustering" its modes through another network.

## 2. Mass-Spring Networks

The "mass-spring" approach for PM corresponds to the quantization of physical matter and time. A particle network is then a network whose nodes are punctual matter points (modeling the inertia of a physical system and defined by a weight and a spatial position) and links are unweighted viscoelastic elements such as springs, dampers, conditional links...(performing the energy transfers and scattering inside the object and defined by their stiffness, damping parameter and spatial conditions).

A simulation is a computation of all displacements and forces' transfers inside the object. Under definite parametric conditions this evolution may correspond to acoustic vibratory phenomena. The transmission of the extensive position variables, through a DAC to a loudspeaker, provides an audible signal that may be considered as the sound emitted by the simulated object.

In the most general situation, a simulation can be described mathematically by a second order differential system:

$$M\Delta^2(\bar{x}) = \sum_{\text{ext}} \bar{F} = -Z\Delta(\bar{x}) - K\bar{x}$$

where  $M$ ,  $K$  and  $Z$  are respectively the square parameters' matrices of weights, stiffness and damping factors,  $\bar{x}$  is the vector of spatial positions of nodes, and  $\Delta$  is the differential operator. Given some initial conditions the system embodies the complete mathematical information that is necessary to run the simulation: it will evolve as a vibratory process back to its equilibrium state what is sufficient to perform a simulation for sound synthesis.

The mass-spring approach is a powerful modeling technique, especially when it is supported by an environment such as CORDIS-ANIMA, that enables, through a unified formalism, the complete design of an "instrument" (exciter, resonator, environments) and embodies the real-time gesture control through force-feedback keyboards.

The main drawback of the mass-spring approach (and of other PM techniques however) is that the system is defined through *mechanical* parameters (weights, stiffness...) and not through *acoustical* parameters like with signal modeling techniques. The model doesn't embody any information on the acoustical behavior of the system - at least, not clearly. Actually, all the acoustical properties are hidden in the *eigen elements* of the mathematical system (they express the duality between mathematical and acoustical properties). The problem is that except in a very few cases (see below) it is very difficult and often impossible to have an access to these eigen elements. Thus, if it is easy to build an "instrument" and to "play" it, it is much more difficult to "tune" it and to foresee what it will sound like.

Another problem is that the modeling itself (i.e., the double quantization of matter and time) lays down some specific constraints and limits on the parameters. Moreover, according to the eigen elements of the network, the modeled object generally behaves very differently from the equivalent continuous model. This may be a big problem if this model is supposed to correspond to a *real* reference, in case of a simulation for imitation. For example, if the network in (*fig.1.a*) below may be a rather good model for a string, the one in (*fig.1.b*) is not especially a good model for a *real* circular membrane such as a gong or a drumhead.

### 3. Modeling Methods for P.M.

To get over these difficulties and to reach a more accurate knowledge of the specific properties of mass-spring networks, we have been driven to put aside the modeling of *real* objects and to focus upon certain classes of networks.

First, the resulting sound signal is necessarily mono-dimensional; so a network can be reduced to its topological mono-dimensional form. That means that the geometrical shape of the object is not a relevant criterion. What is important is only how nodes are linked (topology and parameters).

Then we consider that the mechanical parameters do not vary with time. Thus a network is strictly linear (excitation processes are not discussed here) and its eigen elements (acoustic modes) do not depend on the time evolution of the system.

To have an easy access to these eigen elements, we can choose networks which damping and stiffness matrices are proportional.

$$M\ddot{X} = -A(z\dot{X} + kX)$$

where **A** is the connection matrix representing the topology of the network (e.g., the *closed string* in *fig.1.a*). **k** and **z** are the reduced homogeneous mechanical parameters such as  $K=kA$ ,  $Z=zA$

This reduces the networks under study to a narrow class but offers a complete knowledge of their mechanical and acoustical properties.

Especially such a network is diagonalizable and can be described through its modal representation [Djohar.93], [Incerti.96] that enables to split up an *n*-nodes network into a set of *n* independent elementary oscillators (unitary networks made of a single matter point and a single viscoelastic link). Each oscillator corresponds to an eigen mode of the network and its acoustical parameters (eigen frequency, phase and damping time) can be easily reached from its mechanical parameters (weights, stiffness and viscosity).

For the network, eigen values represent the acoustical modes and the eigen vectors represent the mechanical modes (modal shapes).

At this point, the simulation can be performed through Modal Synthesis rather than through Network Synthesis. Modal synthesis reduces the computational costs (one link per node) and gives mean to control some aspects of the sound. On the other hand network synthesis do not require any previous knowledge on the behavior of the system and allows more complex models, especially non linear models (cracked structures).

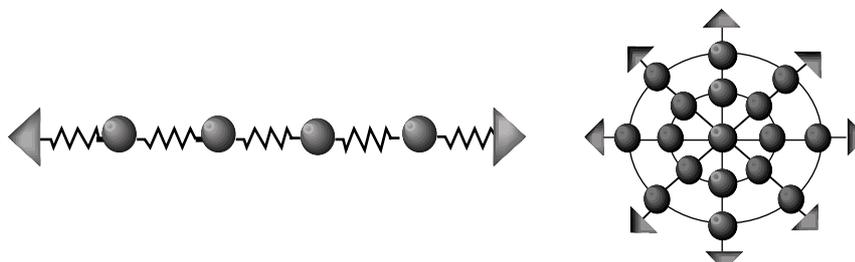


fig.1 - a: closed line, - b: circular plate

#### 4. Parameters

When the modal representation is available, a given topology (defined by a number of modes, and a connection network) can be "tuned": mechanical parameters are adjusted from acoustical one through analytical relations .

These relations are directly dependent on the algorithmic conditions of the computational processes (in this work, they correspond to the CORDIS-ANIMA processes describing the elementary algorithms for masses, springs, dampers). In these processes appear the time-quantization specificity that adds to the network ones (discrete matter). Thus, topology and both classes of parameters are strongly linked and compel the ones each others. Knowing these relations, it is possible to control and use some of the specific properties of the model [Incerti.96].

For example, an  $n$ -masses closed line (see *fig.1.a*) can be parametrized so that its fundamental frequency and damping time correspond to chosen values. But for a given fundamental frequency, the size  $nof$  of the network is limited and its spectrum tends toward harmonicity when  $n$  tends toward its limit value. This constraint does not appear if the study is done with continuous time.

But it is possible to go further and to decompose or combine topologies to control more parameters.

The proportionality condition on mechanical matrices can be extended to a wider class of network; for example, the modal representation is available if the system is such as:

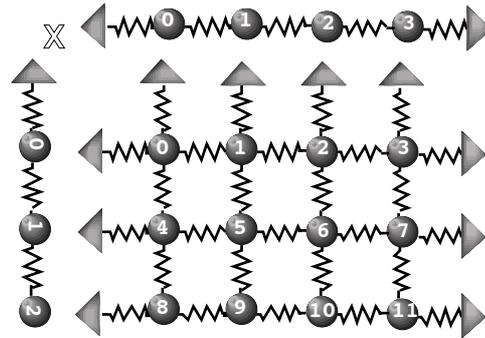
$$M\ddot{X} = -A(z_{in}\dot{X} + k_{in}X) - M(z_{out}\dot{X} + k_{out}X)$$

Such a system can be seen as a two-parts topology. The first part, represented by the connection matrix  $A$  and  $k_{in}$ ,  $z_{in}$  models the inner structure of the object (e.g., the closed-line topology). The other part is proportional to the inertia  $M$  of the system through  $k_{out}$  and  $z_{out}$ . It can be seen as the effect of an external environment of the basic network. Thus the system can be tuned thanks to four parameters. That enables to transform and adjust more aspects of the sound (timbre) with the same control as before. Here again this knowledge may be used to model real physical phenomena or just to improve the potentiality of the synthesis system.

#### 5. Network Combination

To enlarge again the class of networks under study, some combination rules can be drawn up that retain and transmit the knowledge of the modal representation, from the components to the composed structure.

The simplest example is the *direct product*: from two parent networks, a third one is build by replacing each node of the first one by a copy of the second one as shown in (*fig.2*)



**fig.2** : network combination : *direct product*

Even if the modal representation of the resulting network cannot be reached directly, it is completely available as soon as those of the parents are known. A complex  $n.p$ -nodes network is then described through two simpler networks (respectively with  $n$  and  $p$  nodes).

Instead of *direct product*, other combination can be performed such as coupling between two structures or *L-product* [Djohar.93].

This kind of combination had highlighted some interesting properties of particle networks. Especially it seems that physical parameters (mechanical/acoustical) are more relevant than the connection topology to control the timbre of the modeled object. For example, the *closed-line* of (*fig.1.a*) can be tuned to sound like a drumhead, and the *circular plate* in (*fig.1.b*) can be tuned to sound like a string.

Nevertheless, some topology classes present very strong identity. The most evident is one more time the *closed-line*, ("long" network fixed at both ends) that leads to a complete harmonic distribution of modes (basic string model). In the same manner, the *open-line*, free at one of its ends, leads to a harmonic distribution with only half modes and evokes an air column in a pipe .

#### 6. Application to Modes Clustering

Network combination such as direct product can be used to strengthen some aspects of the sound. For example, through the modal representation, it can be shown that the eigen frequencies of the product can be distributed so that the modes of one of the parents (called *spreader*) are clustered around the modes of the other (called *carrier*). The carrier has a few modes distributed on wide area of audible frequencies and gives a macroscopic aspect of the sound (e.g., harmonicity, duration). The spreader is a more diffuse structure with grouped

modes. It acts like a filter or a modulator on the basic timbre (see *fig.3*). Both structures can be tuned separately for a more accurate control.

The resulting models are usually much more sensible to input and output conditions (excitation and recording) and produce smoother and richer sounds with rather cheap networks.

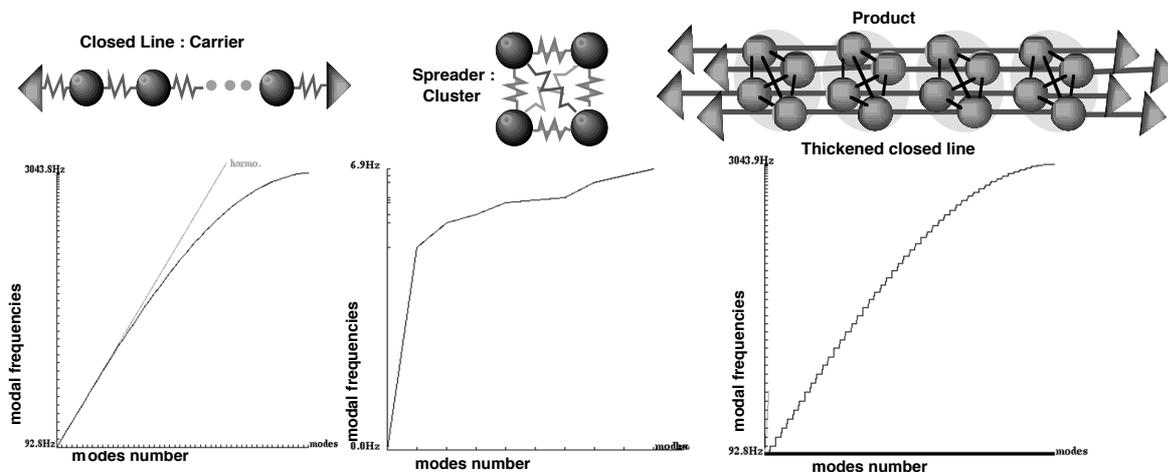
Some experiments produced "non-linear" effects (whereas the model is strictly linear) due to modes beatings and phases ratios. This is very perceptible under continuous excitation : some experiments done under the CORDIS-ANIMA formalism with a bow model [Florens.90] gave very realistic sounds (in the sense that they evoke natural sounds, but not necessarily such or such instrument).

## 7. Conclusion

Mass-spring networks for P.M. synthesis offers a very convenient approach for the modeling of virtual "instruments": the simple combination of elementary modules (masses, springs...) is sufficient to design vibrating systems and perform a sound synthesis, with or without a previous theoretical knowledge on the model.

The mechanical description of production processes as a starting point for "instrument" modeling improves the physical realism of sounds but masks the "musical" properties of the object if the relations between mechanical and acoustical parameters are not available. Moreover, a common misunderstanding concerning P.M. appears in the modeling methods themselves. Suppose one wants to synthesize a "violin sound"; what is exactly to be modeled: the violin as a physical object with its complete body, neck, bridge, strings and bow or just something that will *sound* like a violin? If the goal is just sound synthesis, the second solution is clearly better: synthesis of "violin-like" sounds can be performed with a very simple bow model and a cheap (but completely controlled) vibrating object such as the previous *thickened closed-line* (*fig.3*).

For a conclusion, this work tends to show that if P.M. may really be "The Next Big Thing" [Roads,94] in sound synthesis, many aspects of the modeling approach are worth to be studied more carefully so it will be possible to use P.M. in a relevant way for more efficiency.



**fig.3** : Modes Clustering

## Bibliography

- [Cadoz.93] C.CADOZ, A.LUCIANI, J.L.FLORENS : *CORDIS-ANIMA : a modeling and simulation system for sound and image synthesis - The general formalism.* - CMJ - Vol.17 n°4 - Spring 1993.
- [Cadoz.95] C.CADOZ, A.LUCIANI, J.L.FLORENS : *Musical Sound, Animated Images with CORDIS-ANIMA and its Multimodal Interfaces.* - ICMC proceedings Banff - Sept. 1995 (531-532)
- [Djohar.93] P.DJOHARIAN : *Generating Models for Modal Synthesis.* - CMJ Vol.17 n°4 - Spring 1993
- [Florens.90] FLORENS JL, CADOZ C : *Modèle et simulations en temps réel de cordes frottées.* - 1er congrès Français d'Acoustique - SFA- Editions de Physique - Lyon Avril 1990.
- [Incerti.95] E.INCERTI, C.CADOZ : *Topology, geometry, matter of vibrating structures simulated with CORDIS-ANIMA. Sound synthesis methods.* - ICMC proceedings Banff - Sept. 1995 (96-103)
- [Incerti.96] E.INCERTI : *Synthèse de Sons par Modélisation Physique de Structures Vibrantes. Applications pour la création musicale par ordinateur* - Ph.D. Thesis in Computer Science. - ACROE-INPG - 19 Sept. 1996, Grenoble, France.
- [Roads,94] C. ROADS : *Physical Modeling : The History of Digital Simulation of Acoustic Instruments.* - Keyboard - September 1994 - pp.89-103.

(†) Currently postdoctoral fellow at Electronic Music Studios, Faculty of Music, McGill University, Montreal, Canada.