10 CRITERIA FOR EVALUATING PHYSICAL MODELLING SCHEMES FOR MUSIC CREATION

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ABSTRACT

The success recently encountered by physically-based modeling (or model-based approaches) for music should not mask the deep challenges that remain in this area. This article first proposes an overview of the various goals that researchers and musicians, respectively operating from scientific and end-user perspectives, may pursue. Among these goals, those recently proposed or particularly critical for the coming years of research are highlighted. The article then introduces ten criteria that summarize the main features an optimal physically-based modeling scheme or language should present. With respect to these, it proposes an evaluation of the major approaches to physically-based modeling.

Key words: goals of the physically-based approach to sound synthesis and music creation, languages and schemes, end-user needs, perception, evaluation criteria, bibliographic overview.

1. INTRODUCTION

The physically-based approach to sound synthesis (also called model-based approach, or more simply physical-modeling approach - PM) first appeared at the end of the siwties and has considerably been developed since the late eighties. One can notice that works in the field reflect various aims, goals and, finally, 'philosophies'. In this article, we will accept the general definition proposed in 1990 during the workshop "Physical Modeling, Musical Creation and Computers" [1, 2, 3]: a model will be considered as 'physically-based' when the modeling and the synthesis of the signal of the signal-based approaches is replaced with the modeling and the simulation of a possible origin or cause (from which a sound signal is extracted). This definition mainly emphasizes the design process, rather than the properties of the models themselves: a model is 'physically-based' if during the design process the focus is on the study and the modeling of the most prominent and significant properties of some real-world sound generating mechanisms, no matter what the tools and concepts used to design the model are.

In a musical context, it would not be sufficient to have a specific physically-based algorithm for every category of real sound object. Just as a number of signal-based sound synthesis techniques have been proposed over the years, various physically-based schemes, generic algorithms and standard methodologies have been introduced, capable of generating models for various sound sources. In this article, the approaches will be categorized as the following (see section III): the traditional or numerical analysis approach, the mass-interaction modular scheme, the wave-guide scheme, modal approach, and the black-box non-linear approach.

In 1995, David A. Jaffe proposed *10 criteria for evaluating sound synthesis techniques* [4], covering the modelling and control issue, the efficiency of the technique, the 'interest' of the producible sounds, etc. (Fig. 1).

J1 – How Intuitive are the Parameters?
J2 – How Perceptible are Parameter Changes?
J3 – How Physical are the Parameters?
J4 – How Well Behaved are the Parameters?
J5 – How Robust is the Sound's Identity?
J6 – How Efficient is the Algorithm?
J7 – How Sparse is the Control Stream?
J8 – What Classes of Sounds can be Reproduced?
J9 – What is the Smallest Latency Possible?
J10 – Do Analysis Tools Exists?

Figure 1: *The 10 criteria by Jaffe [4]*

Such a set of criteria presents three interests. It allows: a synthetic representation of the possible uses of a technique, a condensed summary of the main features that may be expected for an hypothetical optimal technique, and a multidimensional evaluation of the existing techniques.

As a result, says Jaffe, the PM approach to sound synthesis has certain advantages. For example, though PM is usually expensive in terms of processing time (J6) and analysis tools are difficult to provide (J10), it naturally proposes physical parameters (J3) that behave well (J4), and a particularly robust sound identity (J5). However, PM is significantly different from signal-based techniques, and all the PM schemes closely resemble each other according to Jaffe's criteria. A dedicated set of criteria is needed.

From an end-user's point of view rather than a technical analysis, the first section of this article discusses the various interests one may find in using PM. Among these, we will dwell mainly on those recently proposed, adding new challenges to research in the field. Then, based on this analysis, 10 new criteria are introduced. Finally, the various schemes are summarized without technical detail and their prominent properties are situated according to the criteria.

2. REASONS FOR USING PM – A SURVEY

Two motivations for designing a physically-based model should be distinguished: one which aims for a better understanding of real objects and musical instruments (as in musical acoustics) and another which is more oriented to sound and music creation. In the first category, the validation of the model is mainly based on a confrontation between its outputs and measures obtained on real objects. In the second, which this article is dedicated to, the aim is to propose models, schemes and integrated tools for a musical use, which, as we will see, involves very different goals and needs.

2.1. Sound Re-Synthesis of Real Instrument: Imitation

Many musicians, especially in popular music, consider the re-synthesis of sound of real instruments as a very important feature. To that aim, PM can be a far more powerful approach than the commonly-used sampling technique: physical models lead to a wider range of sounds and expressivity, whereas each timbre or performance expression must be prerecorded when samples are used. Smith explains that a physical model may be considered in this context as a 'structured sample' with physical parameters sampled instead of air pressure [5].

Such a mimetic use of the PM is often considered as its principal interest. However, this position may be very limiting, since it does not call for a deep empowerment of our creation tools.

2.2. Acoustic Inference - 'Plausibility' of Sounds

Given that we have physical models able to imitate the sound of real instruments, we may then modify the models with no more physically based consideration of any kind [6]. As say Borin *et al*, a physical model can be considered as a 'musical reality generator' of its own [7], whether the produced sounds evoke a real object's sounds or not. However, the possibility of such a process is not sufficient to ensure its interest. We need to evaluate the quality of the sounds thus produced, if possible.

Among other roles, human hearing is helpful in keeping us aware of our surrounding. We know that hearing is innately tied to inquiry into the origin of a sound. Especially, the ear expects two pieces of information: *where* the sound comes from, and *how* it has been produced. As a consequence of the latest, says Risset [8], "synthesized sounds will be more easily accepted by listeners and have a better profile when they lead the subject to think they were produced in some physical manner" by a hypothetical real object.

We may say that a certain "realism" or verisimilitude is needed for synthesized sounds. However, the term realism is far too close to the real world, which we want not to reproduce but to extend. Pearson and Howard qualify the sound produced with physically-based models as "organic and complex" [9]. Borin *et al.* indicate that the prominence of interaction between algorithmic blocks in physically-based models, facilitates the synthesis of "rich" and "homogeneous" sounds [7].

We prefer the notion of physical *plausibility of a sound*. The important feature for a musical sound is not to cause the listener to infer its physical cause, but to present a set of subtle dynamic variations among perceptual parameters that lead the listener to think it was produced in some physical manner. A sound may be far from evocating any real acoustic source while still being plausible. Each synthesis technique may produce plausible sounds, provided it is used carefully. However, since they are based on the modeling of some physical process, physical models naturally lead to plausible sounds, even if they are not designed with reference to any real object.

2.3. Variations of Static Parameters within a Physically-Based Model

Authors usually explain that the modification of a physical parameter within a physical model produces a consistent effect on perception [2, 3, 4]. With a physical model, you will hardly modify independently the perceptual parameters (loudness, timbre…), which tends to be possible with signal-based models. However, you may obtain relevant series of models by modifying a parameter, that is instrumental variations with an overall robust consistency.

2.4. Playing a Physically-Based Model – Sound Vitality

Many authors also agree with the idea that the dynamic behavior and the playability of physically-based models are of particular interest and that PM schemes offer better prospects than signal-oriented methods for the design of expressive digital instruments. First, physical models have commonality of proposing a representation of the dual concepts of force and position. As a consequence, an input signal measured on a transducer can be naturally injected into models [2]. Second, the use of physical modeling tends to avoid the necessity of a *mapping of gesture inputs* on the parameters of signal-oriented models, which is known to be a difficult point.

These remarks also apply outside the scope of real time simulations. Actually, physical models enable an intuitive representation of the action we perform each day with real objects, especially with musical instruments, such as plucking, striking, dumping, etc. They allow the user to deal with *metaphors of the instrumental gesture*. In addition, with PM, a (real-time or deferred-time) gestural input modifies in a coherent manner the various perceptual parameters of sound. Subtle and plausible dynamic variations are obtained automatically, whereas they must be explicitly specified with a signal model – the general problem of the synthesis control field of research. Physical modeling thus tends to displace the origin of these necessary subtle variations, responsible for sound vitality, from the control flow to the model itself. With physical models, we hope that the dynamic evolutions in sounds are automatically plausible and strongly reinforce the illusion of a permanent cause.

2.5. From Multisensoriality to Virtual Reality; A Mean for a Global Approach to Human Perception

Haptic devices with gesture feedback have proven their great interest in the context of real-time playing and are more and more used for virtual instruments [10, 11]. Physical models are particularly promising when using such haptic interfaces, first because of the naturalness of the interconnection they make possible (through the force and position variables and without the need for a complex dedicated layer in the model) and second because they are able to generate relevant gesture feedback.

Extending this analysis from gesture interaction to other categories of phenomena, physical modeling appears to be a relevant paradigm for virtual reality systems, based on multisensorial and interactive simulation, including gesture interaction and sound and visual outputs [12, 13].

In addition, among other questions, researchers in cognitive sciences currently seek a better understanding of the processes involved in the construction of the mental representations of objects [14]. Conversely, other researchers try to identify the necessary and sufficient cognitive condition to trigger the sense of presence of virtual objects [15]. The PM paradigm is relevant for studying this problem; it is a means for approaching perception as a global system. While the signal-based approaches to analysis and synthesis have developed in parallel with researches in psychophysics during the XXth century, PM may be an efficient means for developing new branches in the field of cognitive sciences [8].

Though these considerations may be considered as outside the scope of this article, one should keep in mind that approaching physical modeling only with the point of view of sound synthesis may be restrictive compared to its potential for creating virtual, convincing and expressive sensorial artifacts.

2.6. Practicing PM: a New Approach to Music Creation

The building of a relevant physical model is known to be quite a difficult job [2]. A question is whether a musician could be in charge of the modeling itself, or only be an end-user of preconceived models. The latter is the common response, since physical modeling is usually assumed to require a scientific knowledge rarely possessed by musicians. Most of the works published till now concern peculiar models of categories of real sound structures (membranes, plates, strings, winds, etc.) designed by researchers, and within most of the environments for implementing PM the modeling process itself tend to be hidden to the user, who can only manipulate preconceived models at a high level of activity. From our point of view, a different approach should be encouraged.

Though musicians are not commonly confronted in an intellectual manner with the notions of force, position, inertia, damping, physical interaction, energy, etc. all these notions are intuitively prehensile through our body and our every-day life. Our experience, especially with the numerous users of the GENESIS environment [16], proves that modeling may be accessible to every one, based on what we call an intuitive ‘physical thought’ [17]. Moreover, practicing physical modeling can be particularly interesting for a musician: among other lexical fields, the musical vocabulary employs physical concepts, such as energy, waves, motion, force, etc. – concepts offered by PM. Just as the signal-based approaches to signal processing and synthesis have had a deep impact on musicians and composers’ work, one can imagine that PM may lead to new musical creative processes by displacing the focus from sounds to virtual objects, by developing the use of a specific vocabulary, and finally by changing composer’s mental approach to music.

One can notice that software environments for musical creations based on physical modeling have not encountered an important success so far. Researches in the field should without doubt continue in order to let musician users operate all the necessary changes in their minds, and thus arrive at a physical modeling “philosophy”. As we will see later, the search for such an environment has a strong impact on the features that a physical modeling scheme should offer.

2.7. From Sound Synthesis to Musical Composition…

Recently, Cadoz proposed an innovative approach to composition based on the mass-interaction modular scheme [18]. As Cadoz explains, one may obtain a succession of sound events rather an isolated sound by assembling in a complex structure both high frequency models and low frequency models: the high frequency model will generate the sound, whereas as the low frequency model will be responsible for sound event generation. With his experimental piece pico..TERA, Cadoz demonstrated that it is possible to extend dramatically this idea. pico..TERA is made of a single model with thousands of masses and tens of different “objects” (or models) interacting. The 5 minutes of music of this piece are then obtained by executing this model without any external interaction nor post-treatment.

Such a compositional process presents three major advantages. First, since low frequency models are slightly perturbed in a natural manner by retroaction from sound models, the sound events generated do present convincing short-term evolutions, expressiveness and musicality, such as changes in a rhythm or in the timbre of successive musical events – somehow as a musician would do. Second, the process proves that physical modeling makes it possible to meld within a single paradigm both sound synthesis and computer-aided composition. Third, the compositional process is deeply transformed: the “think physical” dictum we discussed above may be extended to the compositional scale.

3. 10 CRITERIA FOR EVALUATING PM SCHEMES

As proven by the above analysis of PM interests, PM concerns, theoretically as well as practically, the entire musical creation process: from instrumental playing to compositional activity, through instrument design. It may be regarded as a very general means for musical creation, and even more. However, physical modeling must not be approached exclusively from the perspective of sound-synthesis. Following Jaffe’s work [4], we introduce below ten new criteria that we think more relevant for differentiating among physical modeling schemes. Some of them, indicated by an asterisk (*), are directly inherited from Jaffe’s article. The others are specific to physical modeling, and closer to the aims presented in section I.

3.1. Computer Efficiency Criterion

3.1.1. PM1 (*) : How Efficient is the Algorithm?

Physically-based algorithms tend to be more costly in terms of processing time than signal-based algorithm, since not only synthesize sounds but also simulate their physical causes. However, for a given richness of sound, computational efficiency of two PM schemes may be very different, in terms of both CPU and memory requirements. Computational efficiency influences the maximum complexity of a real-time simulation, and the possible number of iterations in improving a “deferred time” model. Although computer power increases, it still remains critical, which we take into account through PM1.

3.2. Phenomenological Criteria

3.2.1. PM2: How Faithful are the Synthesized Sounds?

As say Borin *et al*, “synthesis by PM has the unique feature of taking [the reference to natural sounds for qualitative judgments] as its validating hypothesis” [7]. The PM2 criterion evaluates whether or not a given scheme can lead to sounds comparable to real instruments’, both through ear and signal analysis. PM2 is obviously important when the aim is to reproduce the sounds of a real instrument (see section I). However, it is of a lesser importance when the user is mainly seeking a convincing sound plausibility but does not want to model a specific sound object.

3.2.2.PM3: How Diverse are the Categories of Instruments that can be Modeled?

A scheme may be particularly appropriate for the modeling of some categories of instruments (such as winds, plucked strings, non linear musical instruments, etc.) but less interesting for others. PM3 evaluates the diversity of the real instruments and, more generally, of the real-world sound generation mechanisms that can be modeled in an elegant and efficient manner by implementing the scheme. A scheme that maximizes the criterion PM3 may be particularly interesting for building an environment for musical creation with a general purpose. However, it may at the same time minimize PM2.

3.2.3. PM4: Is the Scheme Exclusively Dedicated to Sound Synthesis or More General?

As noted in section I the physical modeling paradigm is particularly promising in the contexts of Virtual Realities with multisensorial outputs. Moreover, in the specific context of musical creation, the diversity of the phenomena that can be generated covers two challenges. First, as demonstrated in various articles, a visual representation of a simulation may be of a great interest, especially for understanding the model’s dynamic properties [9, 16]. However, while some schemes naturally lead to a relevant visual representation, others don’t. Second, Cadoz’ “composing (with) physical modeling” process calls for schemes that are not dedicated to the modeling of sound structures but, more generally, to the modeling of every real object and the simulation of the instrumental gesture. Given these points, criteria PM3 evaluates whether or not a scheme can be utilized to model non-sounding objects and enable various sensorial interactions, including haptic and visual ones.

3.3. Criteria for Evaluating Usability of the Scheme

The following criteria aim at evaluating whether or not a scheme is a good candidate for being implemented by a musician himself, which we considered to be promising.

3.3.1. PM5: How Robust is Sound ‘Plausibility’?

While modeling, a musician will hardly put into practice the physical knowledge of a scientist. His process may be nothing but exploratory, empirical and intuitive. Certain schemes, when implemented with such an approach do not easily lead to ‘plausible’ sounds. PM5, which we consider as a particularly important criterion, estimates the robustness of the considered scheme.

3.3.2. PM6: How Modular is the technique?

Modularity has been regarded as a very important feature since the very beginning of sound synthesis. Mathews, for example, already considered that modularity is necessary to obtain at the same time generality, power and simplicity, and carefully designed the modular principles of the well-known MUSIC programs [19]. In the context of physically-based modeling, modularity may be approached through various points of view (existence and meaningfulness of basic modules and composing rules, possibility of an incremental modular process rather than a one-shot modeling, etc.), which altogether represent our PM6 criteria.

3.3.3. PM7: How Intuitive and Effective is the Associated Mental Model?

From a cognitive point of view, we call the user’s mental model (or conceptual model) the representations the user builds in his mind regarding a system. The use of a system is not based on its real properties, but on the user’s mental model. A good mental model should let the user anticipate the results of his action and facilitate explorations [20]. The mental model associated with a PM scheme may hardly depend on the knowledge of Physics the user have and on his experience with the scheme. Nevertheless, it can be easier or more difficult to elaborate and implement, depending for example on the intuitiveness of the notions it displays.

Many sorts of mental models may be relevant for a musician – provided it is effective for controlling the scheme. However, we consider that the mental model will be more interesting if it let the user build and handle his models as if they were real objects, and not as a set of equations or theoretical constructions. As a consequence, we propose to measure PM7 mainly by evaluating the *impression of reality* a user may experience in using the scheme.

3.3.4. PM8: How Deep is the Modeling Process Enabled By the Scheme?

As proposed by Cadoz [1], three categories can be distinguished among the models we can build: phenomenological, functional and structural. The recording of a sound is, for example, a phenomenological model. A signal-based model for the re-synthesis of the sound is a functional model. When one does not consider the observed phenomenon but the object that generated it, decomposing recursively this object in smaller interacting objects, and proposing a model for each of the latter, a structural modeling process is performed. As a matter of fact, says Cadoz, a physical model is nothing but the result of a more or less developed structural modeling process. The deepness of a model is the point at which the structural decomposition is stopped and replaced by a functional (or even phenomenological) approach to modeling. Our PM8 criterion then consists in evaluating the deepness of the modeling process associated with the scheme.

It is not *a priori* necessary to perform a deep modeling in order to maximize the phenomenological precision PM2 criterion, particularly in the case of isolated sound events. However, this becomes very important when the model is used in a dynamic context, interacting with third parties. In that case, indeed, a lack in structural intrinsic richness may be revealed. Furthermore, we consider that a scheme that enables a deep modeling process tends to be easier to use. First, it will be modular and second, since the basic modules will be smaller, they may be more comprehensible for the user. As a conclusion, we consider that PM8 is very important. It may somehow be seen as a condensation of the criteria proceeding, from P3 to P7.

3.4. Criteria for the Environment for Using the Scheme

3.4.1. PM9 (*) : Do Generation Algorithms Exists?

Our PM9 criterion studies whether or not there exist algorithms for parameter estimation or model generation for the re-synthesis of a sound or a set of perceptual parameter (frequency, timbre, etc.), and evaluates their effectiveness. Such tools establish a connection between the signal (or phenomenological) space and the physical model space, and thus enable a somehow signal-based approach to PM and provide a great help in designing a model. However, they should be used carefully: one of the major interest of physically-based modeling is to be found in the shift in the mental approach to music creation it calls for, which may be reduced by generalization of these tools.

3.4.2.PM10: Is there a Friendly Musician-Oriented Environment for Using the Scheme?

The PM10 criterion aims at evaluating whether or not an environment already exists for practicing the scheme, and how efficient it is. But this is not sufficient. As commonly argued in human-Computer Interaction, the 'end-user oriented' part of an environment should not be seen as an opportunity to circumvent shortcomings in usability of the 'functional core', but should be designed in order to provide a clear-as-possible interface to the 'functional core'. Translated into our context, this idea shows that a given scheme may or may not be well-adapted for implementation in a musician-oriented environment, depending on its 'innate usability'. As a consequence, in order to maximize PM10 the satisfaction of the previous criteria (particularly P5 to P9) is important. One can observe that PM10 remains very general: environments probably require a dedicated set of criteria. However, given its importance, it was necessary to evoke the question here.

4. A MULTIDIMENSIONAL EVALATION OF THE MAJOR PHYSICALLY-BASED SCHEMES

This section consists of a categorization of the various approaches to physically-based modeling, and an evaluation of these approaches based on the previous criteria

4.1. "Traditional" (or Numerical Analysis) Methodology: the Acousticians' Approach.

For many, the practice of physical modeling in a computer environment is necessarily based on a numerical analysis process. Such a *traditional approach* consists in first constructing a continuous-time model with the laws of traditional physics, and secondly using some numerical analysis technique in order to discretize this model and make it run-able. The digital model is only an 'approximation' of the first, which is presented as 'ideal': a recurrent aim is to evaluate and minimize the divergence or numerical bias.

Ruiz and Hiller's digital string [21], which is the very first physically-based model dedicated to musical sound synthesis, is an example of the traditional approach. The specificity of the work resided in the use of masses and springs meshes for the step-by-step computation of the string wave equation. More recently, other uses of masses and springs meshes as a computation mean were proposed [9]. Nevertheless, other numerical analysis techniques may be employed, as demonstrated in [22, 23] for examples.

The traditional approach is probably the most precise (PM2), and it can be used in any case (PM3). On the contrary, it is not modular (PM6) and its implementation needs some scientific knowledge, so that it minimizes PM7. It is mainly interesting when the aim is to study the physics of an instrument rather than to propose models for creating music.

4.2. Mass-Interaction (or particle) Modular Scheme

The mass-interaction modular approach (Cadoz, 1979 [24, 25]), should not be confused with the Ruiz and Hiller's numerical analysis approach, even though it also uses masses and springs. Within this approach, a model is obtained by assembling, as a network, modules of two types: masses and physical linear and non-linear interactions. Usually, the user is not required to refer to any continuous model of traditional physics, nor to consider the mass and spring network as a numerical analysis method. He rather bases his construction work on intuition, trying to imitate or "metaphorize" the object he wants to model.

The mass-interaction scheme is expensive (PM1) and not very precise (PM2 - we know that simulating a wave equation by using masses and interactions introduces some numerical bias). Furthermore, the mass-interaction scheme is mainly dedicated to the modeling of objects such as strings, plates, etc (PM3): to model a wind resonator, for example, a user would employ a functional approach, in the sense of Cadoz, by using a string-like model opened at one of its extremities.

On the contrary, the basic elements are very elementary models of a piece of matter, that remain pertinent for the human senses (they all can be, for example, perceived through a haptic gesture interface or visually represented, PM4) and can be easily internalized by any user as representations of very basic objects. The scheme is thus deep and highly modular, which enables a particularly interesting mental model (PM6, 7, 8). It is also robust (PM5) since a network of masses and interactions will sound 'plausible', no matter how it was constructed. The scheme thus appears to be a valid candidate for the design of environments for creating music to be used by a musician, such as GENESIS [16] (PM10).

4.3. Wave-Guide Scheme

The wave-guide scheme was introduced by Smith (1986 [26] and 1992 [27]), when he re-interpreted in a physical manner the Karplus et Strong [28] signal-based algorithm for the synthesis of realistic plucked-string sounds. A 1D wave-guide is a double delay line, looped on the extremities, with losses and dispersion consolidated at the sparse points – see [5, 27] for details. As shown by Smith, such a set of filters realizes an elegant and efficient solving of the one-dimensional linear propagation equation. The wave-guide scheme may thus be seen as a peculiar 'traditional' approach – it is, indeed, a particular class of the *finite difference* method. However, being particularly well adapted to sound synthesis, it led to a commercial hardware implementation (Yamaha, VL1) and remains today one of the most used.

A large number of instruments can be modeled quite precisely by using this scheme (PM2), provided, however, that they have a linear resonator (so that the scheme is not the most general, PM3). Parameter estimation algorithms (PM9) are currently under research [29]. Since it models the wave propagation rather than matter in itself, the scheme is specifically dedicated to the modeling of oscillating objects, and particularly sound objects (PM4). It is modular, but its basic module, the delay-filter, can hardly be considered as a physical model in itself (PM6). The mental model it enables is meaningful, but does not seem very efficient when the goal is to let a musician handle the scheme at a basic level (PM7).

4.4. Modal Scheme

Within the modal scheme (or spectral approach – first publications by the end of the 80's by Florens *et* al [30] and Adrien [31]) a vibrating structure is represented through a series of independent elementary oscillators, provided with coupling data. Each oscillator models a mode of the structure, and the coupling data represent the modal shapes of the structure for each mode.

Concerning the PM1 efficiency criteria, the modal scheme is intermediate between the wave-guide approach and the mass-interaction scheme. As the wave-guide approach, the modal scheme is dedicated to the modeling of vibrating objects (PM4) with linear resonators (PM3). It is not deeply modular since the basic modules necessarily model a whole structure (PM6). Since modal data are collections of frequencies, decay time and amplitude weightings, the scheme can be approached with the signal-based vocabulary. This enables a relevant mental model (PM7), particularly efficient for users that are accustomed to the additive synthesis technique, though not deeply based on intuitive physical concepts. The scheme successfully led to software environments (PM10), such as Modalys [32], and efficient generation tools exist (PM9).

4.5. Non-Linear Source/Filter and Dynamic Non-Linear Black-Boxes Approaches

Musical instruments are usually made of a resonating structure excited through a non-linear interaction by quite a simple source (speed bow, constant mouth pressure, etc). During the 90's, algorithms have been proposed utilising this analysis, based on a signal source and a numerical filter coupled by a non-linear retroaction function [2]. Extending this approach, classes of dynamic non-linear systems with a state representation and delayed non-linear feed-back loops were studied, and proposed to musicians as 'black boxes' to be used (Vergez & Rodet, [33, 34]).

The approach, in its whole, is on the border of the physically-based modeling paradigm, since the structural analysis involved is basic (PM8). The associated mental model (PM7) is usable by system control theorists, but could hardly be implemented by a musician. Each model must be analyzed case-by-case, and the approach is not highly modular (PM6). It is based on some structural properties of musical instruments and therefore dedicated to sound synthesis (PM4). In the end, it does not offer an important diversity (PM3), but does offer very good precision (PM2) for specific uses, especially in the case of winds (trumpets [34], etc.).

5. CONCLUSIONS

As a first conclusion, it appears that practicing PM is not – or not only – practicing sound synthesis. The major approaches in PM for music do not aim only at developing new sounds, but rather at proposing new systems for sound and music creation, and at encouraging new creative processes by using these systems. PM thus calls for a 'paradigm shift' in the approaches to sounds synthesis and more generally to musical creation.

The 10 criteria we proposed (Fig. 2) focused on processing cost, on phenomenological interests, on usability and on the existence and validity of software environments. We believe they can be useful for a better understanding of the various important challenges PM covers.

PM1 (*): How Efficient is the Algorithm?

PM2: How Faithful are the Synthesized Sounds?

PM3: How Diverse are the Categories of Instruments that can be Modeled?

PM4: Is the Scheme Exclusively Dedicated to Sound Synthesis or more General?

PM5: How Robust is Sound 'Plausibility'?

PM6: How Modular is the technique?

PM7: How Intuitive and Effective is the Associated Mental Model?

PM8: How Deep is the Modeling Process Enabled By the Scheme?

PM9 (*): Do Generation Algorithms Exist?

PM10: Is There a Friendly Musician-Oriented Environment for Using the Scheme?

Figure 2: *our ten criteria for evaluating PM schemes. (*) denotes a direct inheritance from Jaffe's article [4].*

The criteria permit a multidimensional evaluation of the main PM schemes. As a result, the various schemes do present different characteristics for the end-user, and each one has some specific benefits, depending on the user's needs.

6. AKNOLEDGMENTS

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