Organizing Mass-Interaction Physical Models: the CORDIS-ANIMA Musical Instrumentarium

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ORGANIZING MASS-INTERACTION PHYSICAL MODELS: THE CORDIS-ANIMA MUSICAL INSTRUMENTARIUM

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ABSTRACT

Practicing physical modeling leads to reconsider the relationship with the musical computer, at a conceptual and practical level. This calls for specific learning tools, which fully take into account the specificities of this activity and go further than the traditional concepts of libraries of models and tutorials used in computer music environments. This paper presents a framework, called the Instrumentarium, which addresses this issue in the context of the CORDIS-ANIMA physical modeling system. The Instrumentarium represents in a structured and general way the possibilities offered by the system, by specifying the concepts that define the internal organization of the models. We introduce a functional analysis of CORDIS-ANIMA networks, which is based on the study of several hundreds of existing models. It may be extended to provide a general ontology of models built with other modeling systems.

1. INTRODUCTION

Physical models are increasingly used by composers ([4], [6]), and physically-based software synthesizers progressively reach the commercial market. While modular environments based on signal processing are increasingly popular, only a few modular physical modeling environments exist today: a majority of physical modeling tools come as ready-to-use virtual instruments that only provide an access to simplified parameters of the underlying model and not to its internal structure.

However, practicing physical modeling within a modular environment – instead of using pre-built models – is a privileged way to discover and utilize its full potential [2]. Modularity has obvious advantages over the non-modular approach: it brings generality to the environments in which it is used, and gives more freedom to the user. In return, it demands more skills, time and experience. Within signal-based environments, these difficulties are often dealt with using tutorials and libraries of examples. Concerning physical modeling, this approach is clearly insufficient, since the fundamental concepts that the users have to understand are far from being as widespread as those of signal-based sound synthesis and processing. The diffusion of physical modeling has to face the challenge of finding new tools for transferring conceptual and practical knowledge from expert modelers to end-users.

In the context of CORDIS-ANIMA mass-interaction physical models [1], we addressed this issue by working on the development of a framework called the Instrumentarium [8], which goes beyond the ideas of library and tutorial. The Instrumentarium project aims at providing a general organization of CORDIS-ANIMA models for musical creation as well as practical information, concerning, for example, specific modeling techniques or the use and configuration of virtual objects.

After recalling the principles of CORDIS-ANIMA (section 2), we will present the Instrumentarium project in more details (section 3) and then focus on the functional analysis of physical models (section 4), which is the core of the proposed framework.

2. CORDIS-ANIMA

CORDIS-ANIMA is a modular modeling and simulation system, used for music creation as well as visual animation and real-time multisensorial simulation [1]. CORDIS-ANIMA models are networks of material elements (e.g. free masses and fixed points) and link elements (e.g. springs, dampers and non linear interactions). A link element (or <LIA> module) simulates an interaction between two material elements (or <MAT> modules), as illustrated in Figure 1.

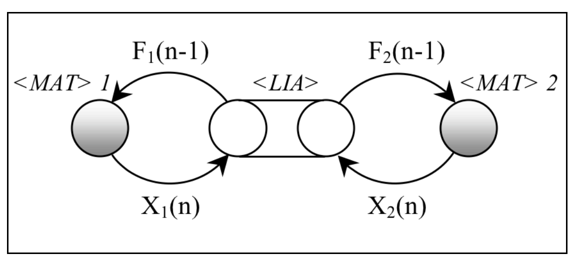

Figure 1. Computation of forces (F) and positions (X) in a basic CORDIS-ANIMA model.

Models used for musical creation usually mix several objects at different frequency scales. *Acoustic objects* have vibration modes in the audio domain and may be viewed as "virtual instruments"; they are in charge of sound production. On the other hand, *macro-temporal objects* have oscillations whose frequency is below the audible range (< 20 Hz), or do not oscillate at all; they produce movements that are used as "gestures" applied to other acoustic or macro-temporal structures, e.g. to excite them.[1] The coexistence of several time scales allows to generate macro-temporal forms and musical structures with CORDIS-ANIMA models.

The work described in this paper is entirely based on models built with GENESIS, a software environment for musical creation that lets the user create CORDIS-ANIMA models by graphical manipulation of the modules on a virtual workbench [3].

3. THE INSTRUMENTARIUM PROJECT

CORDIS-ANIMA is based on a very small number of module types compared to most computer music environments (e.g. 10 module types in GENESIS). This "extreme" modularity has a positive impact on the learning process: discovering the basis of the system only requires to understand a limited number of building blocks, which are associated to simple concepts such as inertia, velocity, stiffness or friction. However, it may be difficult for a non-experienced user to figure out how to build a model given an initial goal. Musical creation with CORDIS-ANIMA requires to master the elementary physical concepts and to organize the models into different levels of increasing complexity in order to articulate the musical ideas. This cannot be done efficiently without a comprehensive representation of what is a model and how it can be structured. One of the primary goals of the Instrumentarium project is to provide such a representation as part of the knowledge concerning musical creation with CORDIS-ANIMA models.

This representation takes the form of an ontology (i.e. "an explicit specification of a conceptualization" [5]) of CORDIS-ANIMA models, which replaces the usual depiction of a physical model as a system composed of an exciter and a resonator. This conceptual part of the Instrumentarium will be implemented in the learning environment of GENESIS. At a practical level, the Instrumentarium will consist of: (1) a presentation of the ontology and its applications to the creation and analysis of models; (2) a set of short documents describing the most common physical objects and modeling techniques, with details concerning their practical use (context, parameter values, reference to real objects or phenomena, etc.); (3) a large library of models, structured according to the principles stated in the conceptual part. We will focus here on the principles and main elements of the ontology.

[1] The word "gesture" is used here in a metaphorical sense, since the movements produced by macro-temporal objects may have amplitude or frequency scales that go far beyond the scales of the human body (e.g. an amplitude of several kilometers, or a frequency of 0.0001 Hz).

3.1. Previous Works

A first general organization of CORDIS-ANIMA musical models had been suggested before the Instrumentarium project began. The proposed scheme is a hierarchy of physical components directly inspired by the analysis of the real chain of elements leading from the gestures of the instrumentalist to the listener (the "instrumental chain"), i.e. exciter, sounding bodies, resonators, environment, etc. It also takes into account the compositional level, with the component types called "Instrumentalists" and "Conductors", which have the same role in a model as their real counterparts.

This approach is consistent, but incomplete. Indeed, the constant reference to the real instrumental situation doesn't take into account the possibility to build models that doesn't share the same structure or couldn't even exist in our world: it is impossible to represent some very simple GENESIS models (e.g. a string model with a negative friction) with this scheme. This shows that a comprehensive representation of CORDIS-ANIMA models should be based on a more "neutral" point of view. Consequently, during the design of the Instrumentarium, we avoided as much as possible the references to the traditional musical situation, to the acoustic instruments or to the perception of sound and music, and focused on the physical level of the models.

3.2. The Ontology of CORDIS-ANIMA Musical Models

The ontology is based on the distinction between the structural and functional aspects of the models and specifies the elementary vocabulary that allows to describe the organization of a CORDIS-ANIMA network without any ambiguity, which is a real challenge considering their complexity and diversity.

From the *structural point of view*, a model is regarded as a set of interacting physical *structures* (Figure 2-a). A structure corresponds to the common idea of a physical object. It is defined as a solid, independent and clearly identified part of a model.

From the *functional point of view*, a model appears as a set of *components* composed together, each one performing a specific *function* and contributing to the global result of the simulation. A function corresponds to a type of physical action that can be performed by a specified part of a model. A component may be a single module (for example, the SOX module, which is in charge of recording a movement), a structure (e.g. a string or a plate) or a set of structures. Any CORDIS-ANIMA object can play various roles depending on the context in which it is used, so it cannot be considered as a component *per se*. Conversely, a function can be performed by many different components.

Identifying the functions that are performed in a model and the associated components is called the functional analysis. It allows to build a functional graph (Figure 2-b), which sums up how the model is organized at this level.

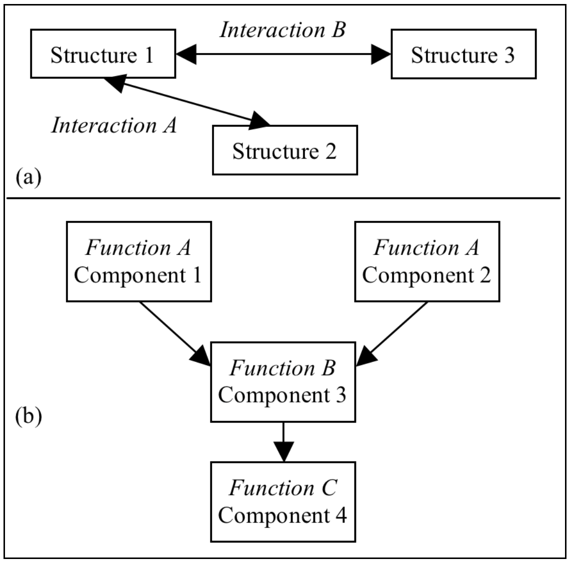

Figure 2. Structural (a) and functional (b) representation of physical models.

The distinction between these two points of view is a key concept of the Instrumentarium. Indeed, separating function from structure allows to describe how a model is organized without having to consider the details which explains its exact behavior. Thus, it is possible to analyze or design models at a higher level than that of individual modules. Compared to the previous proposition, this approach also shifts the focus from physical objects to the more general domain of physical actions, which makes it possible to take into account models with unusual organizations.

4. THE PHYSICAL FUNCTIONS

4.1. Required Functions

Several conditions have to be fulfilled if a model is to produce usable sounds: the model must contain an acoustical structure; this structure must be put in motion, which means that it has be connected to or contain a source of energy; lastly, its movements must be recorded. In most cases, the modeler will want to add damping to the model, unless he or she wants to work with sounds that never fade out.

From these four conditions, we directly get a list of functions that has to be performed in any sound-producing CORDIS-ANIMA model: *Acoustic Generation* (the production of movements at audio frequency by a structure), *Excitation* (the transmission of energy from a source to a structure), *Damping* and *Recording* (Figure 3). The last three functions can be applied at the acoustic level as well as the macro-temporal level, which is important for the generality of the ontology.

4.2. Optional Functions

To go further than these simple results, we carried out a study of the models designed by GENESIS users since its first release, with a bottom up approach. Indeed, in the various models (more than 50,000) that have been built so far, we observed many organizational patterns, which appeared spontaneously and are largely shared. These characteristics led us to consider that these patterns would be a strong basis for our work.

We have reviewed several hundred models in order to find and characterize the recurring components, physical phenomena or modeling techniques. During this process, we identified 5 new functions, which are not needed to produce sounds, but are present in many sophisticated models.

Macro-temporal Generation is the counterpart of Acoustic Generation in the macro-temporal frequency domain. It corresponds to the production of “slow” movements by a structure.

Modification is the action of changing the properties and behavior of a structure during the simulation, including stretching and structural modification [7].

Triggering is a particular kind of Excitation. It corresponds to the beginning of a clearly identified “physical process” (i.e. a causal sequence of physical phenomena) caused by the transmission of energy from a source to a structure.

Measurement is the action of obtaining the value of a physical variable, such as speed, acceleration or frequency. It is possible to build measurement component in CORDIS-ANIMA models, such as the Force-Position transducer. Using such components makes it possible to use measured values to control the behavior of any part of model. This way, it is possible to implement, in a totally physical way, logical operations (such as: “automatically stop the oscillation of structure A when structure B is activated”) that can be used to create complex compositional processes.

Lastly, *Initialization* is the action of putting a structure in a defined physical state (generally expressed in terms of the position and the velocity of its <MAT> modules) in order to use or re-use it for a specific need.

4.3. General Scheme

The physical functions can be integrated into a global organization scheme (Figure 3). This representation focuses on the physical structure, which is in a charge of producing movements (Acoustical or Macro-temporal Generation). This structure can be excited, damped, modified or initialized, and its movements can be recorded or measured. The 4 top functions (Excitation, Damping, Modification and Initialization) are called *interaction functions*, because they correspond to actions that affect the physical state of the structure. On the contrary, Recording and Measurement have no influence on its behavior, so they are called *monitoring functions.*

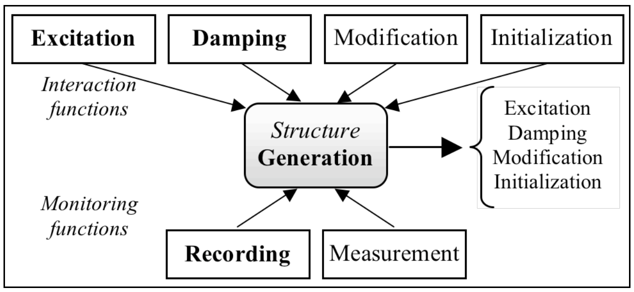

Figure 3. Physical functions applied to a structure. Required functions appear in boldface. This general scheme is the core of the ontology of CORDIS-ANIMA musical models.

Any structure of a model is considered as a virtual agent that can perform several functions through dedicated components. For example, a simple oscillator tuned at 0,1 Hz, can be used to damp an acoustic structure every 10 seconds.

This scheme makes no restriction on the number of hierarchical levels and can be applied recursively: a structure can act on a second one, which acts on a third, etc. This way, it is possible to conceptualize models of arbitrary complexity.

5. CONCLUSIONS

The scheme that we propose for musical CORDIS-ANIMA models is able to represent in a non-ambiguous way the structural and functional organization of complex virtual objects, which are not related to real world instruments and implement unusual sound-generation mechanisms. A rather small set of fundamental and structured concepts allowed us to build a conceptual system that is able to account for the various possibilities offered by CORDIS-ANIMA for musical creation. The conceptual part of the Instrumentarium has so far been validated against a large set of such models as well as more "classical" ones. Additionally, this scheme has been employed in the organization of the models used for the creation of a musical piece, *Utsikten* (O. Tache, 2007).

We are currently implementing the Instrumentarium for GENESIS, so that the proposed ontology can be confronted to the practice of many users over a long period of time, in learning and creation situations. This is the only way to evaluate the relevance of such a complex system and to identify how to improve it. Besides, the design of the Instrumentarium coincides with the release of the first multiplatform version of GENESIS (G^3). We expect that a large community of users will soon support the Instrumentarium project and contribute to its future evolutions.

More fundamentally, our work may open new perspectives for physical modeling in computer music. Current modeling techniques are very different, considering that they are not based on the same concepts and techniques. However, they all represent and simulate physical objects that have the same application, producing sound and music. Building a common ontology for these models would be a decisive step for the diffusion of physical modeling, since it would allow presenting them to potential users in a more understandable and unified way. Thus, we will soon investigate to which extent the ontology of CORDIS-ANIMA we propose could be generalized in this purpose.

6. ACKNOWLEDGMENTS

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