METABOLIC EMERGENT AUDITORY EFFECTSBY MEANS OF PHYSICAL PARTICLE MODELING: THE EXAMPLE OF MUSICAL SAND

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ABSTRACT

In the context of Computer Music, physical modeling is usually dedicated to the modeling of sound sources or physical instruments. This paper presents an innovative use of physical modeling in order to model and synthesize complex auditory effects such as collective acoustic phenomena producing metabolic emergent auditory organizations.

As a case study, we chose the 'dune effect', which in open nature leads both to visual and auditory effects. The article introduces two particle physical models, able to collaborate. The first is dedicated the synthesis of spatial (or visual) dynamics effects of moving sand dunes. The second is dedicated to the rendering of acoustical dynamics of "sounding sands". Altogether, they lead to a multisensorial simulation of sand in dune.

Keywords: auditory effects, metabolic effects, emergence, sonification process, sounding sands,

1. INTRODUCTION - THE NOTION OF SOUND EFFECT

Usually, the notion of sound effects points to electro-acoustic effects and sound processing. We use here a concept of sound effects in a more general meaning, similar to the notion developed by architects working on urban environments. We address a kind of generalization of Schaefferian 'objet sonore': a stable perceptual category, built as an intermediary between the acoustic phenomenon and the source that produces it.

The work we present is based on the repertory of sound effects produced by J.F. Augoyard *et al.* [1] from 'in situ' sound records of urban environments, and categorized by sets of auditors. This repertory contains about 90 effects classified into 6 groups: elementary effects (coloration, delay ...), composition effects (emergence, blur, doppler ...), mnemo-perceptual effects (anamnesis, remanence ...), psychomotor effects (attraction, chain reaction, ...), semantic effects (citation, imitation ...), electro-acoustic effects (chorus, compression, larsen ...).

The paper will mainly deal with 'composition effects', especially emergent and metabolic effects, and more specifically on the effects that are produced by sand in dunes. It aims at proposing a model able to simulate both the visual and auditory effects of such structures.

2. PHYSICAL MODELING AND METABOLIC EFFECTS

In Greek, 'metabolos' means something that is always changing or in perpetual metamorphosis. A metabolic effect is a collective phenomenon that emerges from a multitude of interacting items producing short-live shapes that are constantly appearing and disappearing.

A common acoustic metabolic effect occurs in a crowded public place such as market, in-door pool, cocktail meeting: innumerable sources of voice, steps, shocks, stand out against the background, immediately dissolved and replaced by others. Others frequently observed metabolic effects are visual structures such as flames in fires, or shimmers on water or silk. A metabolic effect is also a classical figure of rhetoric, referring to the instability of the relations between the elements of a set, and the possibility to switch over between themselves. Several composers (Iannis Xenakis, Michel Chion, Steve Warring, Steve Reich) used 'metabolic effects' in their musical works.

The notion of metabolic effect raises the complex question of emergence. A metabolic effect cannot be explicitly described by any notation. It appears by itself, in an unpredictable manner, under specific dynamic configurations of multiple interacting elements confined in a same space. Some works in Physics [2][3] and Computer Graphics [4] [5] proved that interacting particles models can produce complex emergent dynamic evolutions such as turbulence, fractures, agglomeration, chaotic pilings, etc.

3. THE EXAMPLE OF 'DUNE EFFECT'

The auditory metabolic effects that can be observed in urban environments usually merge physical objects and human voices. Since they have a too strong semantic connotation, they cannot be analyzed and synthesized easily.

Instead of the formers, we chose for our case study another natural phenomenon which is a typical case of dynamic metabolic organization: 'the dynamic of granular materials' of which a beautiful example is the 'sand piling phenomenon'. Granular materials show off a number of complex dynamic behaviours (structured piling and growing, chaotic surface avalanches, auto-similar sub-piles constitution and internal collapses) producing two kinds of visual metabolic effects:

- The *surface avalanches* that carry out a two-states metabolic effect. A well-shaped pile emerges at each moment to our perception, arising from a relaxation process between two states of the pile, before and after the surface avalanches. The growth reinforces the perception of the shape while the avalanches destroy the contour which causes the clearly-cut perception of this shape.
- The *internal collapses* that break up the volume of the well-shaped pile. This destruction comes with the formation of internal sub-piles that are similar to the entire pile.

The pile contour as well as the auto-similar sub-piles appear clearly to our perception and cognition, although they are still short-lived and transient.

Granular materials can also produce sounds effects, such as those of the sounding sands. A well-known reference is the 'Sand-Drums' in 'Dune' by F. Herbert [6]. For ages, explorers were astonished by sounds produced spontaneously during the motion of large volumes of sand. Darwin mentions similar events in 'Naturalist's Voyage in the Veagle' in Brazil and Chili. In China, in the Ton-Fan region, about 880 before J.C., one mentions that a dune, called 'Singing Mountain', sounds as roll of thunder when sliding on it [7]. Iberian nomads told of spirits playing drums in desert and pre-Islamic poets invoked often musical sands [8].

These narratives are probably not completely fanciful. Some records prove that some sand landscapes produce spontaneously sound effects. These phenomena are neither well studied nor understood today. Scientific accounts distinguish two types of sounding sands: squeaking and booming sands [9]. 31 booming dunes have been discovered [10]. Authors use words as 'howls', 'thunder', 'drums', 'bells', 'horns', 'frogs', 'cello', 'insects', etc. Some records of sounding sands are available on the web: Booming Sand of Badain-Jaran, Sound of Frog-Sand, Kotohiki and Kugunari by S. Miwa, Sound-recording of booming sand by B. Krause, D. Criswell, J. Metzner, M. Bretz.

4. MODELING OF THE 'SPATIAL DYNAMIC DUNE EFFECT'

These descriptions enable us to provide qualitative description of sounding sand metabolic effects. From the capabilities offered by physically-based particle systems, we aimed at obtaining similar effects by means of a physically-based particle model.

The first idea was to model realistically the sand material, composed of a large number of grains and complex interactions between them. Such an approach, however, would lead to quite a complex physical model - too complex for being usable and computable reasonably. A more straightforward modeling was necessary.

We then designed a physically-based particle model of the 'spatial (visual) effects of granular materials''. With this model, we aimed no more at modeling the realism of the matter itself but at restituting the emergent pertinent dynamic features.

This second model was designed with the CORDIS-ANIMA system [11], simulated at 1 KHz and visualized at 50 Hz. It is composed of a few number of particles (less than 300) in simple interactions (visco-elastic buffers) between themselves, and with a simple non-linear interaction with the ground (dry friction).

Figure 1 shows some snapshots of the obtained simulation, with different values for the physical parameters (elasticity between the particles and friction with the ground).

As a result, we obtained the five pertinent visual figures of 'the Spatial Dynamic Dune Effect' : (1) piling, (2) internal heterogeneous constraints, (3) surface avalanches, (4) internal collapses, (5) auto-similar sub-pilings.

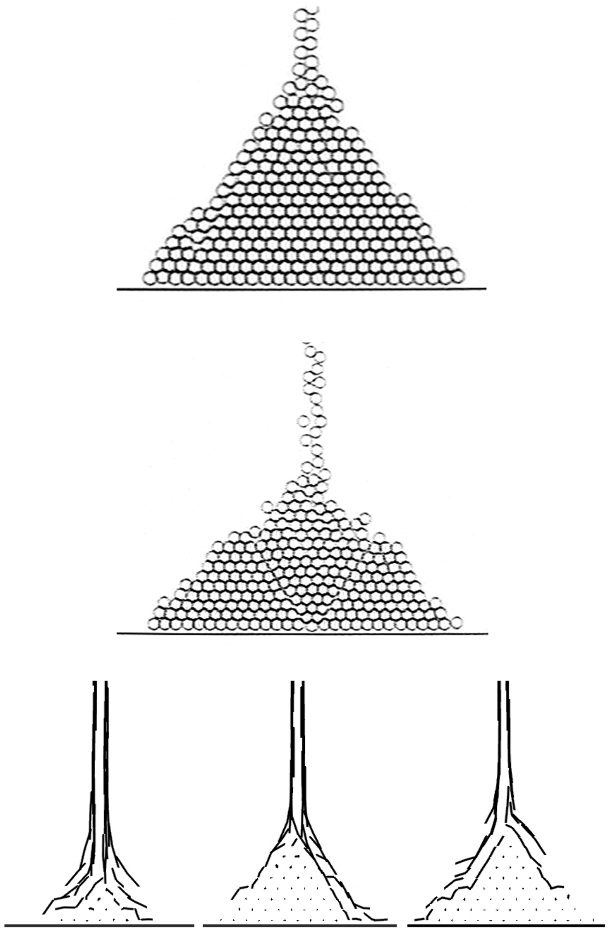

Figure 1: *The five main pertinent spatial figures of 'the Spatial Dynamic Dune Effect' we obtained: (1) piling, (2) internal heterogeneous constraints, (3) surface avalanches, (4) internal collapses, (5) auto-similar sub-pilings.*

5. MODELING THE MUSICAL STRUCTURE EMERGING FROM THE 'SPATIAL DYNAMIC DUNE EFFECT'

From the previous relevant visual model, we aimed at obtaining a valid sonification process able to produce the sound effects listed before: unpredictable 'Drumming', 'squeaking', and 'booming' effects.

5.1. First trial

We tested a first ‘sonification’ process based on three steps:

- Modifying the physical parameters for the above visual sand model in order to obtain vibrations and oscillations within the model during simulation;
- Computing the physical model at the acoustic bandwidth.
- Listening the deformations at some places of the pile by means of virtual loudspeakers.

Although this process is quite complex, it proved to be unconvincing and led to fat too simplistic sounds from the acoustical and musical point of view.

A new step of modelling was performed in order to obtain the emergence of the pertinent categories of the sound effects from a specific model.

5.2. The structure of the Acoustic Model

We first performed an analysis of the sand piling obtained with the first visual simulation. From this analysis, we designed a physically-based particle model of a "musical instrument", thought as an acoustical model corresponding to the spatial model of sand, but specifically dedicated to the acoustical phenomena. Playing together, "in parallel", the first is dedicated the synthesis of spatial dynamics, the second to the rendering of acoustical dynamics.

Actually, the visual sand piles can be decomposed in numerous layers with different physical structures.

In the lower layers, all the particles are compressed by the upper levels, and then they are still linked by visco-elastic interactions, such as in a 2D plate or in a 3D block of elastic matter. These layers behave as a quasi-homogeneous vibrating structure.

The intermediate layers, that compress the lower levels, are less compressed than them. Within, the particles are still interacting between themselves, but only by means of multiple micro-percussions. These layers play the role of a complex macro-exciter for the underlying layers.

The upper layers are composed of the particles falling on the pile causing macro-percussions on the intermediate layers.

In the complete granular phenomena, all these layers are continuously melting with each other, from the bottom to the top of pile. However, we performed a functional approximation by decomposing the piles only into only three layers (figure 3.a):

- Layer 1: a compressed layer that behaves as a quasi-homogeneous vibrating structure. All the particles within are *always* linked to each other by visco-elastic interactions, such as in a block of elastic matter.
- Layer 2: a set of colliding particles constrained in a confined space, that compress layer 1. This intermediate layer is also a vibrating structure, but particles interact within it through multiple micro-percussions ('maracas' structure, see [12]).
- Layer 3: the upper particles falling and colliding the layer 2. This layer plays the role of a complex macro-exciter for the underlying layer, producing chaotic confined micro-percussive motions.

With the aim to validate this approximation, a computer analysis of the visual simulations has been performed. The following figure (Figure 2), shows that, within the layer 1, the particles are quite immobile and always linked, as if they were inside an elastic vibrating surface.

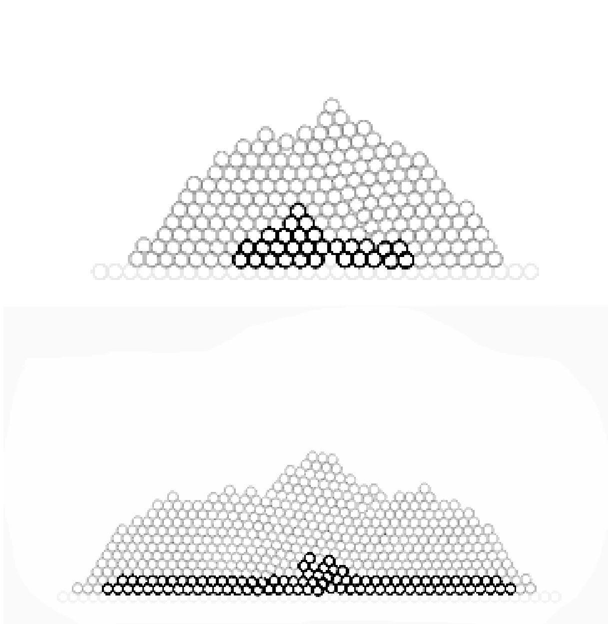

Figure 2: *The detection of the lower layer in two different simulations.*

We modelled this acoustical structure within the GENESIS software [13], based on the CORDIS-ANIMA system and dedicated to sound synthesis, as following (figure 3.b):

- The layer 1, called 'Sand-Plate', was modelled as a string (or a plate) by a set of punctual masses linked with visco-elastic interactions.
- The layer 2, called 'Multiple-Exciter', was made of some particles confined between the layer 1 and a nearest buffer, called 'Confinement Buffer'. They are colliding between themselves and with the previous vibrating structure.
- The layer 3, called 'Macro-Exciter', was modelled with a small number of particles falling freely from time to time, and colliding the particles of the 'Multiple-Exciter'.

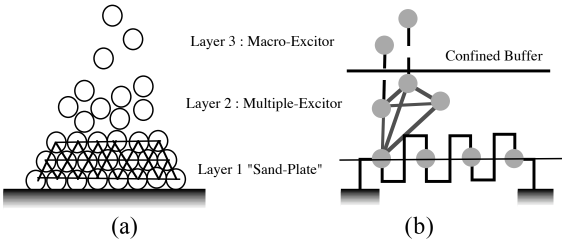

Figure 3: *Instrumental structure of Sand piling: (a) approximation of the spatial dynamic organization, (b) corresponding acoustical particle model*

5.3. Results and further works

With this simple instrument organized in 3 layers, successively exciting each others, and without the modeling of the dynamic macroscopic transformations, as those that occurs in sand piling, we obtained many of the relevant acoustic effects of musical sands: rare re-excitations causing drumming sounds, huge reverberation, and squeaking effects with unpredictable re-excitations and vanishing.

We have to pursue with the modelling of the dynamic transformations of the instrument: growth, contour modifications and internal collapses. We planed to model the two first by aggregating from time to time an arbitrary set of Multiple-Exciter with the 'Sand-Plate'. The boundaries conditions and acoustic property of the ‘Sand Plate’ would be, thus, simultaneously modified. The internal collapses would be modelled by breaking the ‘Sand Plate’ from place to place during its dynamic evolution.

6. CONCLUSION

The model we proposed here is a two-level model based on physical interacting particles paradigm:

- The first one is dedicated to the 'Spatial (visual) Dynamic Dune Effect'. It was drawn at the scale of macroscopic spatial non-linear phenomena, rather than at the scale of the real granularity of the material. Thus, it is more efficient to calculate, it runs in real time, and it is easier to control.

- The second model derives from the first. It was drawn to obtain the macroscopic pertinent organizations of sounds, i.e. the sound effects of sands.

One result of this work is the methodology we employed, based in two chained stages The first one is dedicated to the spatial aspects, and lead to visual pertinent effects. The second consists in extracting a second structure to model relevant acoustic effect.

Thus, we defined a method that enables to combine in a close relation the spatial effects, i.e. the "visual image", and the acoustical effects, i.e. "the auditory image", in a complex physical and perceptual phenomenon. The first results, given above, encourage us to use this methodology to model others emergent and metabolic effects, such as those listed in the 'Sound Effects Repertory' referenced at the beginning of the article.

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