Case Studies of Physical Models in Music Composition

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Abstract

Physical modeling in computer music has been developing for twenty-five years. An assortment of algorithms, often in the form of "self-modeling" by musician / engineers, has accumulated and become available to composers. These software instruments have become material for composition and unveiling the range of designs forms the focus of this report. To a large extent, schemes applied in the works cited are reminiscent of schemes which employed "real" instrumental material in 20c contemporary music. We can test for uniqueness in the physical modeling approach and the likelihood that it is grist for "composers to continue to do what composers do" as new material is added or swapped for old.

1. Introduction

The world of techniques for computer sound generation has become vast. For its part, the physical model class of techniques was a foreseeable outcome of physics research encountering fast computers. Digital simulation spawned numerical experimentation as a tool in which models are iterated over time to observe behavior (weather forecasting and studies of jet engine turbulence are illustrative of this tool's revolutionary impact on other domains). Castagne lists five physical modeling approaches in music[1]: 1) “traditional” wave equation, 2) mass or particle interaction, 3) waveguide, 4) modal, and 5) nonlinear source / filter “black boxes.”

One dozen brief descriptions representing practice with subclasses 2-5 have been collected from composers to see if taken together they allude to something new. Apologies are given upfront, that more is left out than is included. In this vast world (with its continually changing ecology of techniques), there are many musics, music makers and potential collections such as this one. Putting together these brief snapshots is necessarily limited to what is known and nearby.

2. From the music

I have freely extracted essences from writings and correspondence on composers' use of physical models. Each refers to a piece of music. Together they provide a read-out on current practice and it is hoped that a read-through alongside a “hear-through” of accompanying sound examples will build the picture. Technical descriptions are beyond the scope of this paper, but may be found in a number of the references cited.

Hans Tutschku
Eikasia (1999) modal, Modalys

> *Eikasia* is my first work with physical modeling. In all my previous electroacoustic pieces, I used processed recorded sounds. My research was to reach a sound complexity with pure synthesis comparable to natural sounds.
>
> I began with a palette of sounds modeled and organized by means of their physical representation in the computer. During the realization, I compared them to their real origins, and from this starting point reached a wide sounding scale: from abstraction to realistic image[2].

Paul Lansky
Things She Carried (1996) waveguide, STK Flute

> Do you spend a lot of time trying to emulate the sound of "real" instruments or is the sound that's never been heard before usually the magic ingredient?
>
> I am interested in being able to emulate real instruments but mainly in the sense that I can get them to assume unreal proportions. For example, I've been using Perry Cook's flute physical model for a few years, but my favorite way of using it is to construct a model of a flute which is about 20 feet long and has a diameter of 3 feet. It produces great sounds[3].

Claude Cadoz
pico.. TERA (2001) mass interaction, GENESIS

> Recently, Cadoz proposed an innovative approach to composition based on the mass-interaction modular scheme. As Cadoz explains, one may obtain a succession of sound

> events rather [th]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... may be extended to the compositional scale.[1].

Andrew Schloss

Can You Hear the Shape of a Drum? (2004) modal, drums

> In 1966, esteemed mathematician Marc Kac wrote an article called Can You Hear the Shape of A Drum? The article was a serious mathematical treatment of different boundary conditions of a vibrating membrane; the mathematics are extremely complex but the idea can be thought of in simple physical terms: Does a shaman's square-shaped frame drum sound different from a round one? I first encountered that article 30 years ago, and now I am finally able to act on it in my own artistic work [4].

Matthew Burtner

S-Morphe-S (2002) waveguide, singing bowl

> The acoustics of a soprano saxophone and a singing bowl are molded into a single instrument. Through the use of physical modeling synthesis the audience can experience a real-time performance of a soprano saxophone with the virtual body of a singing bowl[5].

S-Trance-S (2000) waveguide, bowed string

> ...the saxophone sound, the bowed string sound, and the combined metasax/string physical model sound are transformed into a series of hybrid instruments that are performed live by the saxophone and transfused into independent timbral screens... In trance, a medium passes under the control of some external force. In "S-Trance-S" this takes the form of the saxophone acting as a controller for the string physical model. As if in a dream or hallucination, different morphological forms are generated as the energy of the controller is transfused into the medium. These hybrid forms then act as the ghost-like extension of their archetypes, exploring states of metamorphoses[6].

David Jaffe

Racing Against Time (2003) SoundMAX, SynthCore

> One innovation in “Racing Against Time” is the use of the Radio Drum to control physical models of automobiles, jet planes and “weird strings.” The automobile model... consists of a nonlinear dynamics model of engine spark plug firing, with the timing of a V8 engine. These impulses are then filtered and modified by non-linear processes to simulate the exhaust system of a race car. The surface of the Radio Drum controls the throttle of the engine, while the height above the surface controls the engine load. The mapping of the throttle is in three overlapping horizontal strips so that it is easy to simulate up and down-shifting. Other controls available to the performer include the amount of engine “damage” (misfiring, etc.) and the characteristics of the muffler[7].
>
> (Tim Stilson, on the model itself)
>
> What was always most interesting to me... ...was that by playing with the dynamics of the filters in the [engine model's] feedback, one could get some very interesting and realistic higher-order dynamic spark timings, which sounded like various one-cylinder 2-cycle engines I had heard while growing up (always sounding like they were about to die), or like a Harley-Davidson engine (i.e. various fun subharmonics of the

main rpm, or even nicely chaotic timings, etc.)[8].

Gary Scavone

Pipe Dream (2003) waveguide, STK saxofony

Pipe Dream is... exploring subtle wind instrument overblowing effects. In this work, all sounds are generated using real-time computer-based saxophone-like physical modeling algorithms implemented with the Synthesis ToolKit in C++. The algorithms are performed with a new MIDI wind controller called The Pipe. The controller makes use of a variety of sensors, including buttons, potentiometers, and accelerometers which respond to breath pressure, finger pressure and tilt[9]. I basically took 4 saxofony algorithms and assigned them to separate channels for a quad setup. ...I also mixed in 2 more saxofonies which were equally panned across all 4 channels. Then I did a bunch of things with overblowing and unrealistic "breath" noise gains into the algorithms[10].

Juraj Kojs

Garden of Dragon (2003) waveguide, corrugated tube

The Voice of the dragon is the name given to a group of Japanese children twirling flexible plastic tubes above their heads. The burst of tones that emerged from each musical pipe soared and dropped with rotational velocity. A corrugated plastic tube, in fact, produces pleasant sonorities while rotating in a circular motion.

Singing corrugated tubes became popular in early 70's when a toy called hummer was introduced to the market. The hummer is a corrugated plastic tube about one meter long... When whirled in the air, the tube produces a series of pitches, starting from the first harmonic to its overtones.

This piece presents a communication between the virtual and real singing pipes. The Max/MSP physical model extends the possibilities of the real tubes in several areas: vibrato, pitch and amplitude control, and noise to pitch ratio. The acoustic tubes control the virtual choir of tubes using the fiddle~ pitch tracker of Max/MSP[11].

Achim Bornhoeft

Virtual String (1997) waveguide lattice, stretched string

With it's acoustic manifestations of non-existing objects "virtual string" musically describes the border between an abstract and concrete form of sound perception. The software used for this piece ("vstring") offers a graphical interface to a physical model of a string. Although this was never intended to be a compositional tool, the very intuitive approach to the different parameters of the model was my inspiration to make a piece with it. In vstring, several software sliders control the string tension, stiffness or damping, the type and position of the string's excitation and the frequency response and position of the virtual pickup placed upon it. As only one static configuration could be saved in an audio file, every transition had to be accomplished with many successive and slightly varying slider positions, thus utilizing a technique reminiscent of the animation of a cartoon[12].

Juan Reyes

Wadi Musa (2001) particle interaction, CLM maracas

Given the South American nature of the instrumentation, performers, sound texture and style, the model of the maracas was chosen as a contrasting synthesized sound... polyrhythms are the result of combinations, somewhat chaotic between durations, shake rate, seed quantity and resonances of the shell.

The model of the maracas is a very flexible algorithm because it can help generate various timbres ranging from wooden maracas or plastic maracas with synthetic parts to tambourines and wind chimes. It can produce other sounds like the afuche, the sekere, the cabasa or exotic sounds / performances such as throwing a maraca from one hand to the other. In the model, beans can be ordered in different ways and can be manipulated directly by toggling filter states, probabilities of collision, bean size and quantities[13].

Chris Burns

Hero and Leander (2003) waveguide, Pd networks

The sonic character of the feedback network is varied and idiosyncratic. Complex, swooping pitch contours with continuous micro-alterations of timbre are typical, while the continuously varying delay lengths produce shifting, inharmonic pitch relations. Depending on the gain settings, punctuating noisy explosions may also be frequent. Because the network disregards some of the traditional tuning techniques for physical models (especially polarity inversion), it is likely to enter marginal and turbulent states. The system's behavior is emergent; the output is musical, articulate, and often surprising.

The unpredictable behavior of the destabilized feedback network, enhanced by the algorithmic generation of many of its parameters, is the primary feature...[14].

Torsten Belschner

SonoMorphis (1998) [interactive image and sound installation] waveguide, VL-1

As one of the installation's aesthetic goals is the bodily impression of the generated object on the user, a sound synthesis technique was in demand, that is able to both render a visible object's genuine sound thru all its user-inferred alterations in shape and space in a plausible way, and to be abstract enough where needed to not duplicate a real-world artifact. The technique of choice is known as physical modeling which derives the emerging sound from the physical properties of an assumed object, i.e. its shape, material, excitation mode etc.

Based on associative relationship to the genome's textures, each acoustic representation has first been assigned a set of material properties, causing its basic timbre. Second, the genome's shape is taken into account, controlling the representations' basic modes of vibration and their reaction to parameter-induced deformations. Third, the single graphic objects' current spatial positions are mapped to the sound space, rendering their horizontal movement as well as their proximity to the user[15].

3. Summary

Key concepts in the descriptions above can be distilled in comparison to practice outside the domain.

Helmut Lachenmann

...Zwei Gefühle... Musik mit Leonardo (1992)

Lachenmann does not use electronic sources, but instead reduces the sounds of conventional instruments to their most primitive constituents. He burrows in behind the brilliant, resonant, exuberant tones of familiar instruments and finds what is hidden away in their attics and basements. He then recycles these found remnants into new compounds, rather like splicing genes to create new life-forms[16].

Harry Partch

The Bewitched (1955)

Harry Partch experimented with tones even lower than those produced by the Bass Marimba and eventually arrived at the present Marimba Eroica. The instrument is fashioned from individually hung Sitka Spruce blocks placed over cave like resonators about the size of a piano. The wave length of the lowest bar is more than 50 feet, making the performance space an important part of the instrument. Ideally, the performer should, in Partch's words, cultivate the aspect of a hero of the Trojan War, and in furious passages, "convey the vision of Ben Hur in his chariot, charging around the last curve of the final lap"[17].

3.1. Manipulated identity

Similar quests are found wherein musical sources *assume unreal proportions* (Lansky's flutes), or provide a range of physical *shapes* (Schloss' drums), supplant one instrument with the *body of* another or explore *hybrids* (Burtner's sax / bowl and sax / strings), or magnify certain *effects* by pushing them beyond their usual amounts (Scavone's sax overblowing and breath sound). All reference the known instrumentarium. Starting from existing identities, they are the result of Frankenstein-luthiers working to inflate size, distort shape, hybridize identity, and amplify particular timbral qualities. Such instrument designs could be said to result from *splicing genes*. But within a physically plausible space, leaving perceptual schema intact.

3.2. Abstract to concrete perceptual spaces

Escaping the plausible means disengaging available perceptual schema. Some have manipulated their models to provide a *wide sounding scale: from abstraction to realistic image* (Tutschku), to describe the *border between an abstract and concrete form of sound perception* (Bornhoeft's strings) and to provoke a *communication between the virtual and real* (Kojs's singing pipes). Such designs play at edges within a model's parameter space.

In these abstract zones, models are allowed to *enter marginal and turbulent states* where t*he output is musical, articulate, and often surprising* (Burns), achieving for example, *chaotic combinations* yielding polyrhythms

(Reyes, maracas), or *some very interesting and realistic higher-order dynamic(s)* (Stilson, engine). The most abstract are comprised of networks of interacting modules, the composer's design exploits sound sources in which *the system's behavior is emergent* (Burns) and must be newly learned (though perhaps it retains traces of its physical origins).

3.3. Unified paradigm

The "think physical" dictum can achieve *sound complexity with pure synthesis comparable to natural sounds* (Tutschku) and *derive an emerging sound... from an assumed object* (Belschner). It is a way of imagining and designing music derived from experience, but with a path beyond. The most abstract systems are learned by observing their response to stimuli and changing conditions. Prodding such a model is like prodding a new instrument, and the prodding itself (a physical or imagined physical act) can be composed or algorithmically organized. Cadoz extends this *single paradigm [to] both sound synthesis and computer-aided composition.*

Contributors to this paper are many, some wittingly others not. Thanks go to all and especially to those who responded to my email canvassing.

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