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Sound, Music and Motion
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MUSIC: ARS BENE MOVANDI

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Introduction

I thank Richard Kronland-Martinet for inviting me to this exciting Symposium, and I wish to welcome the participants from everywhere in this Laboratoire de Mécanique et d'Acoustique (LMA), where I have been working for more than thirty years.

In my presentation, I shall give a few instances of the importance of motion in sound and music, and I shall evoke some early research. I shall end my speech with a demonstration of an interactive process of accompaniment I started in the Media Lab of M.I.T. and pursued in LMA, using a Disklavier, a mechanized acoustic piano built by Yamaha.

About the importance of motion

My presentation is a keynote speech. The keynote - **A** 440 Hz - is given by the motion of a tuning fork.

***Demo: tuning fork – held by hand, then touching a table*

You can hear this **A** because the vibratory motion of the tuning fork is propagated to your ears by the air. The intermediate vibrations of the table act as an impedance adaptor between the fork and the air.

Sound is very important on earth because we live on Earth, a planet which has an atmosphere, unlike the moon. Mechanical motions (such as hitting, blowing and scraping) produce perturbations in the atmospheric pressure, and these perturbations will propagate over substantial distances, even in the presence of obstacles that would stop visual signals. Thus evolution has favored the appearance of the sense of hearing, a kind of remote touch, which is extraordinarily sensitive to vibratory motions – for instance one can hear 1000 Hz vibrations of a membrane even when their amplitude is less than the dimensions of a single atom.

The sense of hearing gives warnings about motions occuring in the surrounding environment: this is invaluable for predators as well as for their potential preys.

Perception and action take place in a universe where interactions are mostly mechanical. True, most people hear music today through loudspeakers, and there is a lot of communication through telephones. However the evolution of living organisms has occured in a mechanical world, and our senses are well equipped to detect motions in the environment.

In particular hearing is able to infer the ***where*** and ***what*** of the auditory signals, that is, to locate the source of acoustic sounds and to infer their causality, that is, the mechanical process which produced them

Where does the sound come from : hearing can follow the motion of a sound source from far away to close to us.

Sound1_ChowningFlyingEngine

This was an example synthesized by John Chowning around 1970. Actually the motions we hear are illusory: the sound sources are two fixed loudspeakers. Our hearing interprets certain specific features of the stereo sound as those of a moving sound. In particular Chowning has simulated the Doppler effect to reinforce the feeling of motion and speed:

Sound2_Chowning Doppler

This has lead to a milestone of kinetic music, Chowning 's *Turenas* – which should be heard in its original 4-track version.

Sound3_Chowning, Turenas

At the Groupe de Musique Expérimentale de Marseille, Laurent Pottier has developed *Holophon*, an advanced software for computer music which permits to specify illusory motions – this research is pursued by Charles Bascou.

What causes this or that sound in the following examples?

Sound4_Percussion, in Risset's work Passages

These sounds seem to be produced by percussion - hitting skin or metal instruments.

Sound5_BrassMorrillFM2sounds_3s

This sounds like someone blowing a trumpet.

Sound 6_Vocalises synthesized by Johna Sundberg

Wasn't this a barytone warming up?

However all these sounds were all produced by direct digital synthesis, without resorting to any performer or acoustic instrument. The authors were myself, Dexter Morrill and Johan Sundberg.

So our perception has developed so as to deal with a mechanical world, but the digital production of sound and images can now imitate - or escape - the constraints of mechanics. Yet if one wants to produce sound with strong identities and significance, one must understand what cues our perception uses to give us information about our environment.

Researchers studying musical performance, specially Johan Sundberg and Neil McAngus Todd, have shown that pleasing musical accelerandi or rallentendi are similar to the ways athletic runners speed up or slow down (people like Jesse Owens or Usain Bolt)

This may be a key to naturalness. Evolution has happened in a mechanical world. ***Physical modelling*** makes sounds by simulating the motion of objects, taking in account the laws of physics. An example like that one suggest its cause ...

Sound7_CadozBouncingBall

namely a bouncing ball. Actually Claude Cadoz used no ball to produce this sound at ACROE in Grenoble around 1980: instead, he had the computer calculate the timings of the bounces of a falling abstract mass from Newton's law and elasticity data.

One of the earliest applications of physical modelling to sound was the song "Daisy", synthesized by computer in 1963 by John Kelly, Carol Lochbaum and Max Mathews at Bell Telephone Laboratories. The computer articulates the lyrics thanks to a physical model of the vocal tract, which moves between target shapes corresponding to the vowels. (Max's synthetic piano-like accompaniment did not use any physical model).

Image2_VocalTractShapesHaskins

Sound8_Daisy1963_16s

The computer has an electrical aceent, but the lyrics are quite comprehensible *(Daisy, Daisy, give me answer, do, I'm half crazy all for the love of you...)*. Stanley Kubrick remembered this in his film *2001: A Space Odyssey*.

Physical modelling of sounds has been developped from the 1970s by Pierre Ruiz, Claude Cadoz and others. It tends to produce sounds with a strong identity and presence, for instance the impressive trumpet simulations by Christophe Vergez, and recently the clarinet-like synthesis performed here in LMA by Kergomard, Guillemain and Voinier. When using physical modelling, one does not have to limit oneself to sounds related to the mechanical world: one could model imagined worlds where the law of physics would be different.

Max Mathews had started computer sound synthesis in 1957 with a different approach, namely computing the sound signal directly. John Chowning and myself have attempted in the 1960s and 1970s to synthesize novel musical timbres. Many of those timbres we stumbled upon lacked a strong sense of identity and of presence. We found that it was easier to impart a vivid identity when we generated sounds that could be interpreted by listeners as having been produced by a mechanical process – such as hitting, plucking, scraping, blowing, bowing. We also got some agressively artificial sounds could hardly be called musical.

St Augustinus has written '*music is **ars bene movandi***"– the art of moving well, a graceful dance of sounds. This statement is more than a metaphor.

According to Johan Sundberg and his colleagues in Stockholm, "our listening refers to experiences of movement": thus "an aesthetically pleasing performance is similar to a graceful motoric pattern".

Video_DVD ICA-ACROE 2005-2009, 2: Miroirs by Chi Minh Sieh

These graceful motions have been generated with physical models. The author is Chi Min Sieh, a dancer who has worked in ACROE with Annie Luciani on applying physical modelling to image animation.

Motion is important in many cases. A bicycle will only stand if it moves. The sections of a musical works are called *movements*. People long dreamed of achieving perpetual motion, but science states it is impossible – even though Victor Hugo argued that science itself is a perfect example if perpetual motion. Any way, *perpetuum mobile* is a musical form, illustrated from Paganini to Ravel and Arvo Pärt.

Image3_Fraser Spiral :

One often says “seeing is believing”. This “Fraser spiral” indeed looks like a spiral. However let us follow the curve: it actually consists of concentric circles. Passive looking is not enough. Moving along is believing.

Here is an illustration of a similar pitch circular motion:

Video_ circle of pitch by LoïcKessous

In this example, action and perception are combined. This relates to ***enaction***, a notion on cognition introduced by Francisco Varela and emphasized in the work of ACROE in Grenoble.

Musical performace is sensitive to the acoustic environment. Around 1990, Simon Bolzinger and myself have shown that pianists playing in small rooms try to compensate increased room dryness by playing louder, even when they cannot succeed compensating: then some of them think that the keyboard has got harder.

Audio and sub-audio

Now periodic vibrations at audio frequencies are heard as pitched sensations. Slow sub-audio frequencies are perceived as modulation envelopes, as trackable changes of amplitude, not as as pitches.

I shall play a cluster of sine waves of frequencies 125 Hz, 128, 131, 134, 137, 140 Hz: how does it sound?

Sound9_Cluster125_128

Here is an effect of the phenomenon if beats: the beat frequency is a sub-audio 3 Hz. Thus one can slow down a recording of speech without changing pitches. Here is an example by Daniel Arfib slowing down a recording of the word “langsam”.

Sound10_Arfib : “Langsam” 21s

This can lead to paradoxes. We shall hear beats: are they slower in the first part of the example or in the second part

Sound11_v/2v

Most listeners hear the second part as a little faster. But the second part was deduced from the first by **doubling** the speed of the tape recorder. So subjective rhythm is not just chronometry.

Here I want to argue against

The myth of the resonating body *(le mythe de la résonance du corps sonore)*

Rameau’s idea was that vibrating bodies produce a series of sub-vibrations, called harmonics, which occur at frequencies that are integer multiples of the fundamental frequency. According to Rameau’s view, the intervals between harmonics play an essential role in harmony. Rameau thought that resonating bodies - *la résonance du corps* *sonore* – produced harmonic components : according to him, this was a natural foundation for his theory of harmony. However most **resonant** bodies will not produce an harmonic motion : percussive sounds, such as bells, gongs and drums, even the piano, have *inharmonic* spectra, that is, the frequency components are **NOT** equally spaced in frequency. Only sustained quasi-periodic sounds – such as bowed violons, wind instruments or voiced sounds - have harmonic spectra.

Producing inharmonic sustained sounds is very difficult with usual acoustic instruments, but it is easy with computer synthesis. Thus Chowning, in his work *Stria*, has used a scale related with the specific inharmonic structures of the sounds he synthesized, and he was able to preserve a notion of consonance with unusual scales and tones.

Musical instruments controlled by gestures

Let me go back to the vibration of the tuning fork. It only carries two informations: its pitch, informative about the frequency of vibration, and its loudness, related to the amplitude of the vibration. A strictly periodic sound does not convey a flow of information: sound is informative only insofar as it varies. If the sound is produced by an acoustic source, variations must be produced by modifications of this vibratory source. In the case of musical instruments, such modifications are usually produced by the motions of the musical performer, by the gestures of the instrumentalist.

The art of musical instrument makers has to take in account the physical laws of acoustics as well as the specifics of both auditory perception and human motricity in order to construct machines that will effectively convert the energy of the motions of the performer into audible acoustic energy.

Gestures, musical performance

The performer controls his or her instrument by gestures that are specific to that instrument. These are expert gestures: the instrumentalist has to be overtrained to be able to fullfill the demands of virtuosity of the score. John Sloboda has shown that even gifted musicians need thousands of hours of training to perform instruments at a professional level.

Human gestures act, but they also bring information about the body and the outside work.

Archetypes of musical instruments and of instrumental gestures

Claude Cadoz has proposed a typology of musical gestures. Marcello Wanderley has performed revealing analyses of the gestures produced by performers. He has pioneered the study of the expressive role of looking at the gestures of musical performers.

I shall not discuss this here. I just want to mention that there are two basic archetypes of instruments: the violin player controls his sound from beginning to end, while the percussionist, as soon as he or she has triggered a sound, can attend to the next one. In this respect, the voice and the wind instruments are similar to the violin, while paino, harpsichord, harp, are similar to the percussion. Digital instruments use the protocol MIDI (Musical Instrument Digital Interface). Performance nuance is easier to control through MIDI parameters for percussion-type instruments that for voice-type instruments, even though certain MIDI wind controllers send variations of parameters throughout the note, such a as breath and lip pressure (Kergomard, Guillemain and Voinier used such a controller for the real-time performance of their clarinet simulations).

A present challenge for research on performing with digital instruments is to capture gestures and to map them to significant musical parameters. Yesterday the workshop adressed this challenge with the motion capture tutorial by James Yang. The meeting NIME - New Instrument for Musical Epxressions – is dedicated to this problem. I shall show two short video examples from the group of Daniel Arfib who did work on that here.

Here is Arfib controlling spectrum

Video6_volantArfib26

Now a virtual percussion   VV

Video7_BatterieVirtuelle69s

In the 1970s, Manfred Eaton demonstrated the control of music through brain waves and the *biofeedback* - a difficult endeavour pursued by Atau Tanaka, David Rosenboom, Richard Teitelbaum, Eduardo Mirando and Joel Eaton. In CNMAT Berkeley, Adrian Freed is working on wearable instruments: clothes that sense the motions and turn them into musical effects.

Expressivity in musical performance, deviations

In music, one expects expressive performances: the instrumentalist must deviate in appropriate ways from a mathematically accurate rendering of the score. The computer has facilitated further understanding of musical performance, permitting studies by analysis – detecting the deviations realized by performers and interpreting them – but also studies using the paradigm of ***analysis by synthesis*** – evaluating by ear the effect of such or such deviation from an accurate rendering. Here is a simple early example from Bengtsson and Gabrielson: the beginning *The Fledermaus (The Bat)* by of Johan Strauss. The second version of the example is much more expressive; it differs from the first version only by timing deviations occuring only in the time domain

Sound12_ChauveSourisGabrielson38s

In the early 1970s, Max Mathews has done revealing performance studies by synthesis with the hybrid real-time system Groove, permitting to use non-conventional controllers such as this 3-D potentiometer;

Image8_Groove3Dwand

We shall hear one very short section of Ravel's quartet, realized on Groove with performance deviations specified by two musicians:

Sound13_RavelQuartet (Zukofsky)

Sound14_RavelQuartet (Mathews)

The obvious differences show that this system allows for expressivity.

Now a few words about

Motion in hearing and other senses

The living organism has to integrate the signals it receives from the various sensory modalities. The concept of motion could be a key paradigm for the understanding of various aspects of sounds, in particular its relation with image.

Usually one mentions visual dominance, but sound is more dynamogenic: small children cannot refrain from dancing on music with a strong beat, they will not dance on a periodic recurrence of images. Galileo had musical monks beating time.

Speeding up is exciting, slowing down is depressing, even when the slowdown is circular and endless. I shall play a paradoxical sound which slows down yet ends higher, which also goes down in pitch but ends higher, and also seems to rotate in space faster and faster: there is a sort on conflit between a strange slowing rhytm and an accelerating circular motion.

Image9_EscherCascade

Sound15 UpDownSloFastRotate

Dance is of course body motion with music. N+N Corsino will speak about their association and differentiation. I just want to show a short excerpt of an extreme synchronization between sound and lighting in the ballet *Phosphones*. The music was composed by the late Emmanuel Ghent, who worked a lot on rhythmic coordination. The unsually precise synchronization was made possible here by the real-time system Groove of Mathews and Moore: with the help of the kinetic sculpto James Seawright, Groove produced the control signals for both the music and the lighting. The dancers belong to the company of Mimi Garrard, who did the choreography.

Motion universals

Are there motion universals? Researchers from MIM – Musique et Informatique de Marseille, a musical group created by Marcel Frémiot – has tried to find some universals of motion, in the hope to apply the same analysis tools to both instrumental music and electroacoustic music. The elementary motion components selected were called *Semantic Temporal Unit*s (in French *Unités Sémantiques Temporelles*, UST)– 19 of them at the moment, such as Fall, Rotating, Stationary, Suspended ... The results of analysis are encouraging, but is too early to conclude whether these are really fundamental components of motion, or if there is some arbitrariness in the choice.

I shall not conclude the first part of my presentation: I just meant to introduce this symposium on music and motion, a rapidly expanding field. The meeting will be the occasion of an exchange of new research data. I apologize not to attend – I am sorry to have to leave after my presentation because I am going to morrow to the Musicacoustica Festival in Beijing, China, then to a meeting on the Csound synthesis software. So there is a lot of hustle and bustle those days about computer music.

Interactive disklavier performance

Now I shall demonstrate an interactive process of accompaniment I have developed in Media Lab, M.I.T. and in Laboratory of Mécanique and Acoustique of C.N.R.S. (L.M.A.), using a *Disklavier*, a mechanized acoustic piano built by Yamaha. This is a special interaction, in which the key motions of the pianist trigger a response in terms of motions of mechanical keys rather than motions of a loudspeaker membrane: the live pianist is accompanied by a virtual partner playing on the same piano an accompaniment which depends on what the pianist plays and how he or she plays. So all sounds are in the acoustic domain.

I shall perform the demonstration at the piano after a couple of video examples.

VideoCNRS:
http://videotheque.cnrs.fr/video.php?urlaction=visualisation&method=QT&action=visu&id=394&type=grandPublic

VideoLM: Demo Duet for one pianist: 1 recording, 2 feedback
(symétrie/translation/fractalisation/polyrhythms/arpèges dont le tempo dépend de l'intensité du jeu du pianiste)

VideoMESH, Lille, Théâtre du Nord, 3 février 2009: démonstration du Duo pour un pianiste sur Disklavier (circa 28 mn)
http://live3.univ-lille3.fr/video-campus/concert-diskclavier-jean-claude-risset-2.html

VideoCIRMMT, Montréal, McGill University, 17 mars 2011 : conference with demonstration in English of the Duet for one pianist on Disklavier (1h26mn)
http://www.cirmmt.mcgill.ca/activities/distinguished-lectures/Risset