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Leonardo

Sculpting Sounds with Computers: Music, Science, Technology

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Source: *Leonardo*, Vol. 27, No. 3, Art and Science Similarities, Differences and Interactions: Special Issue (1994), pp. 257-261

Published by: [MIT Press](#)

Stable URL: <http://www.jstor.org/stable/1576064>

Accessed: 18-11-2015 11:19 UTC

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Sculpting Sounds with Computers: Music, Science, Technology

Jean-Claude Risset

COMPOSER AND/OR SCIENTIST?

I am a composer and a research scientist. I am thus exercising two activities that are highly different in their goals, methods and criteria.

Yet these activities are not independent; they somehow nurture each other. My scientific work on sound synthesis and perception brings with it novel possibilities for sculpting sounds, and I take advantage of those possibilities to make music. My musical activity raises stimulating problems for my research. There is intelligence in hearing: My musical experience helps my research by providing reference points, short-cuts and insights.

Before briefly describing my musical activity and its relation to science and technology, I would like to emphasize the inspiration that music can bring to science and technology.

SCIENCE AND TECHNOLOGY CAN BENEFIT FROM MUSIC

There is little need to recall that music has benefitted from science and technology, but the less obvious inverse is often forgotten or even occulted. For instance, mathematicians who know about Farey series tend to dismiss the fact that Farey was not only a geologist, but primarily a musician and a musicologist whose work on the frequency ratios involved in musical scales suggested the introduction of these series [1].

Music has had a kinship with scientific disciplines for many years. It may be argued that some theories inspired by music were magical rather than scientific, from Pythagoras's "harmony of the spheres" to Kepler's system of the planets. However, the questions and demands raised by musicians were quite challenging and inspirational to science and technology. Pythagoras's application of arithmetic to the observation of musical vibrating strings, for example, was physics in the making.

The organ may be considered the first information machine: the performer, touching the keyboard, specifies information that is decoupled from the energy (provided by the pump) that actually produces the sound. The organ's keyboard was the first in history, appearing long before the alphanumeric keyboard of typewriters and computers. In fact, the organ key may have been the first switch. Four centuries before Fourier, organ makers implemented Fourier synthesis in so-called mutation stops: timbre was obtained by adding the sound of pipes tuned as harmonics of the intended tone.

In his musicological treatise, *Musurgia Universalis* (1650), Kircher describes many musical automata, such as mechanically driven organs. In such devices, musical information was coded on a cylinder with appropriately placed pins, or on a

punched paper tape: as early as the fourteenth century, the notion of a stored program was put to work in such devices [2]. This way of storing music implicitly used Cartesian coordinates long before Descartes developed them. To establish his experimental laws of dynamics, Galileo did not measure time with stop-watches: He was helped by musically trained monks tapping a regular beat.

As Diana Deutsch and Frederick Hunt remind us [3,4], many great scientists were practicing musicians—Pythagoras, of course, but also Plato, Kepler, Galileo, Huygens, Leibniz, Newton, Euler, Helmholtz, Raman, Einstein, Heisenberg and Feynman. Jon Appleton believes that "music inspires the kind of rational thought necessary to produce scientific work." He quotes Saminsky: "The acoustical substratum of music . . . makes music a correlative of the universe in the same sense that mathematical norms are" [5].

British historian Geoffroy Hindley suggests that the notation of polyphonic Western music played a decisive role in suggesting Cartesian coordinates, which then made possible the scientific developments of calculus, dynamics and differential equations [6]. Many concepts such as logarithms, modulo and groups were used implicitly in music before being defined in mathematics. According to Hellegouarch, the careful consideration of musical phenomena could inspire more intuitive and holistic mathematical approaches. Fifty years before Chomsky, the Viennese musicologist Heinrich Schenker introduced a theory of tonal music calling for the notion of generative grammar.

Music has also been very inspirational in the field of computers. One could say that the idea of artificial intelligence was first proposed in the field of musical composition. Around 1840, Ada Lovelace, who worked with Babbage, the designer of the Analytical Engine (a mechanical precursor of the digital computer), wrote the following:

[The Engine's] operating mechanism might act upon other things besides numbers, where objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also suscep-

ABSTRACT

The author is active as both a composer and a research scientist. The article emphasizes the inspiration that music can bring to science and technology. This is first shown through a number of historical examples, from classical Greece to the computer age. Problems involving the use of the computer to calculate musical sounds are discussed. The author describes the esthetic incentives in his computer compositions and explains how they relate to his research work on sound synthesis, sound processing and auditory perception, including paradoxes and illusions. The conclusion contends that art and science bring about complementary kinds of knowledge.

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Manuscript solicited by Jacques Mandelbrojt.

Received 14 May 1993.

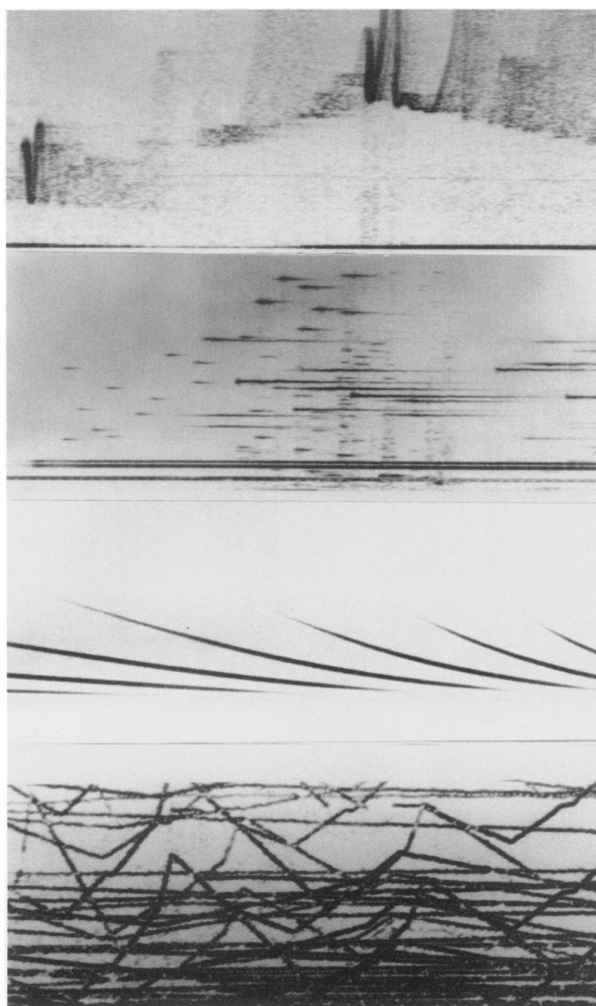


Fig. 1. Images of musical sound. These images display a sound spectrograph of four different computer synthesized sounds [18]. The duration of the portion represented is 2.4 sec. The frequency is plotted as a function of time; the amplitude is coded in terms of darkness. The four images show that one can generate diverse morphologies of sound, including quasi-fractal sounds in the case of the two bottom ones.

could be recorded. It could also be converted into electrical signals and thus processed using electrical techniques. These techniques were rather crude until the advent of electronics, starting in 1906 with the invention of the triode. Lee de Forest proposed this new device—a tube with three electrodes—and named it the “audion” because his goal in developing it was to produce electrical oscillations in order to create musical sounds. Electronic instruments followed, notably the singing antenna, which Theremin demonstrated in 1920 to Lenin, and the Martenot, used in hundreds of compositions by composers such as Varèse, Honegger, Jolivet, Messiaen and Murail.

The advent of the digital coding of signals opened much broader possibilities for sound control. It made it possible to calculate sounds with an explicitly chosen physical structure, while earlier sounds were only the audible traces of oscillations in either a mechanical or an electronic world—with peculiar idiosyncrasies. This was a kind of Copernican revolution of which many people are not quite aware yet. In developing acoustic and even electronic instruments, sound designers were concentrating their efforts on the mechanisms giving rise to these oscillations. Now, with the generality afforded by digital coding and computer programming, constraints of sound production are, in principle, eliminated. The images in Fig. 1 show that sound synthesis can generate diverse morphologies of sound (including quasi-fractal sounds, in the case of the two bottom images). The issue is no longer what sound one can produce, but what sound one chooses to produce. The listener and the listener’s perception become the central criteria for artistic choice.

This situation revives the stand of Aristoxenus against Pythagoras. According to Aristoxenus, the foundations of music are not in number ratios, but in the ear of the listener. Computer synthesis strongly confirms this view. I have, for instance, produced sounds that seem to go down in pitch when their frequencies are multiplied by 2—a striking effect that is contrary to intuition and common sense. Similarly, I have produced beats that seem to slow down when one doubles the speed of the tape recorder on which they are played [10]. These effects exemplify the idiosyncrasies of perception. Clearly, a musical design hastily embodied in terms of frequencies or beat rates can be completely distorted

tible of adaptations to the action of the operating notation and mechanism of the engine. Supposing, for instance, that the fundamental relations of pitched sounds in the signs of harmony and of musical composition were susceptible of such expressions and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent [7].

Music has often led the way for significant advances in computer science and technology. The digital coding of sounds, now used in telephone and outer-space transmission as well as compact discs, was introduced in 1957 by Max Mathews to produce computer music. Mathews’ modular music synthesis programs, from MUSIC3 (1959) to MUSICV (1967), were the earliest instances of block diagram compilers, or modular programs with data flow, which were later used for the simulation of electronic circuits [8]. In their effort to synthesize sounds by simulating vibration mechanisms, Ruiz and

Cadoz [9] did pioneering work in what is now called virtual reality. The attempt to find methods of controlling synthetic sounds through gestures, as with musical instruments, led Mathews and Moore to develop real-time systems on dedicated computers—the forerunners of today’s personal computers and workstations—as early as 1968, and Alonso and Appleton to implement special signal-processing hardware before 1975. Real-time operation raises problems that can be clearly formulated in terms of musical control. Efficient solutions are provided by the MAX graphical programming environment, which was developed by Miller Puckette for musical purposes but is also used for advanced applications of real-time computer control.

CALCULATING SOUNDS

About one century ago, the progress of technology revolutionized the way we relate to sound. For the first time, sound

by its implementation if due regard is not given to its adequacy to perceptual mechanisms. In fact, the relation between the physical sonic structure and the heard effect is more complex than was ever realized previously, especially in the case of sound structures that are hard to produce acoustically but easy to manufacture by computer. One believes this is so because the sense of hearing has developed in a mechanical world: this sense attempts to find out how the sound was produced mechanically, rather than measuring its physical parameters.

Here again, the demands of music production have been inspirational in the field of psychoacoustics, that is, the science of the relationship between the physical structure of sounds and their auditory effect. The exploration of the musical possibilities of computer sound synthesis has strongly contributed to the uncovering of the intricacies of hearing and their *raison d'être*.

For instance, the ear usually has no difficulty in recognizing whether a sound arriving at the ear with a moderate intensity has been uttered loudly and far away or softly and close by; yet, at the moment, no technical device can achieve that recognition. In 1964, I performed a study on the simulation of trumpet sounds, which until then could not be imitated in a realistic way with the computer. My study showed that the main cue for the brassy quality was not a specific frequency spectrum, but rather the fact that this spectrum varies with the intensity so as to grow richer when the amplitude increases [11]. Based on such a cue, one can understand how the ear can infer the loudness at the source and the distance of the source at the same time.

The work of Chowning has demonstrated by synthesis the validity of the ratio of direct to reverberant sound energy as a distance cue, as well as the strength of a frequency glide simulating the Doppler effect to suggest rapid movements of sound sources that are, in fact, illusory. His piece *Turenas* is a milestone of kinetic music [12]. His demonstrations represent important scientific knowledge, but also essential artistic expertise: the feeling of energy in an instrumental performance is related to the energy of sound production at the source rather than to the physical level at the place of the listener. If this were not the case, spectators in the last rows of concert halls would be deprived of the sense of fortissimo. It is important to

understand the cues for giving listeners a sense of energy without deafening them with decibels, as music broadcast by loudspeakers too often does.

OVERVIEW OF MY MUSICAL WORK WITH THE COMPUTER

In this brief description, I shall indicate esthetic incentives in my computer compositions and suggest how they relate to my research work.

Among my musical desires are those of using a wide vocabulary of musical sounds (including and going beyond the vocabulary of musical instruments), of sculpting those sounds and of exerting compositional control at the level of the sound itself—not only composing with sounds, but composing sounds. I want to give due regard to the harmonic dimension and to stage close encounters between acoustic sounds played by live musicians, audible traces of a real world and synthetic sounds suggesting an imagined, illusory world or a separate, internal reality. It is my goal to appropriately stimulate perceptual mechanisms so as to make this internal world intriguing and captivating.

My pieces *Computer Suite for Little Boy* (1968) and *Mutations* (1969), realized at Bell Laboratories, are often considered the first substantial music works entirely synthesized by computer. They implement the scientific developments that made it possible to imitate acoustic instruments—such as brass, clarinet, piano and percussion—and to compose the internal structure of sound, in particular by

- synthesizing gonglike or bell-like tones composed as chords with a prescribed harmony, hence prolonging harmonic control within the realm of timbre
- dispersing in time harmonic compo-

nents that usually sound together, just as a prism disperses white light

- intimately transforming “inharmonic” sounds, that is, sounds made up of non-harmonically related components. By changing the amplitude envelopes of the components, I could leave the underlying harmony unchanged but influence the listener toward either focalized, synthetic perception (hearing separate sound objects or events) or distributed, analytic perception (hearing textures)
- implementing pitch paradoxes. For the compositions mentioned above, I manufactured tones with fractal structures (in other words, tones that look similar when examined at different scales) that seem to glide indefinitely up or down in pitch, or seem to go down in pitch but end up much higher than where they started.

Mutations, for example, is a metaphoric journey from discontinuous pitch scales into a continuum of pitch. This transition happens through going to higher harmonics separated by narrowing intervals.

My pieces *Dialogues* (1975), *Inharmonique* (1977), *Moments newtoniens* (1977) and *Passages* (1982) set up “close encounters” between synthetic sounds and acoustic sounds produced by live instrumentalists. In addition to the previously mentioned techniques based on new scientific developments, they implement the following:

- melodic and harmonic developments by means of compositional subroutines based on sets of pitches and durations treated in a quasi-serial fashion (in *Dialogues*)
- the use of inharmonic tones with ambiguous pitches (in *Inharmonique*)
- the implementation of rhythm para-

Fig. 2. Duets for One Pianist. The pianist pushes certain keys while the computer pushes other keys depending on what and how the pianist plays.



doxes—for instance, beats that seem to consistently speed up, yet end up much slower than they started (in *Moments newtoniens*)

- the transition to a voicelike timbre by careful control of the “animation” of a tone (in *Passages*).

In my compositions for four-track tape, *Songes* (realized at the Institut de Recherche et de Création Acoustique Musique [IRCAM] in 1979) and especially *Sud*, (realized at the Groupe Recherches Musicales in 1985), I bring together the worlds of synthetic and natural sounds. These two different worlds are made to merge by means of several sonic transformations, such as

- cross-synthesis (imparting to the spectra of one sound the dynamic contour extracted from another sound)
- resonant filtering, or imprinting a scale onto natural sounds with indefinite pitch (such as the sounds of the sea).

Songes can be considered a voyage from reality to an illusory, dreamy world devoid of material constraints. In *Sud*, the real and the synthetic worlds gradually merge; the “found object” of a recorded sea wave serves as a genetic cell that permeates much of the composition, from the level of the sound object to that of global musical form—from the microstructure to the macrostructure of the music.

In later pieces realized in Marseille, such as *Voilements* for saxophone and tape (1987) and *Attracteurs étranges* for clarinet and tape (1988), the encounters between the soloist and the tape are made even tighter than in *Dialogues*. The tape part comprises sequences synthesized in non-real time, but molded according to performance nuances based on a real-time performance—a conjunction implemented by Frédéric Boyer in our Equipe d'Informatique Musicale (IM, at the Laboratoire de Mécanique et d'Acoustique du CNRS and the Faculté des Sciences de Marseille-Luminy). These two pieces also include recordings of the soloists (Daniel Kientzy and Michel Portal) that were subsequently processed by computer. The research work of Daniel Arfib, Richard Kronland-Martinet and others at IM has led to new techniques for the intimate processing of digitized sounds, allowing one, for instance, to stretch a recorded sequence in time without affecting the frequency aspects [13]. These techniques call for time-frequency or time-scale representations such as the Gabor or the wavelet

transform, and even the modelling of a given sound in terms of a prescribed synthesis model. This can bring to sound processing the flexibility inherent in synthesis.

In my *Duets for One Pianist*, realized at the Massachusetts Institute of Technology (MIT) and at the Laboratoire de Mécanique et d'Acoustique (LMA) in Marseille (1989, 1991), I introduced the first live interaction between performer and computer that takes place entirely in the acoustic domain. The pianist plays on a Yamaha Disklavier, which is an acoustic piano with sensors and motors. The computer “listens” and elaborates another musical part, which it “plays” on the same piano (see the keys held down without hands in Fig. 2): this part is sensitive in various ways to what and how the pianist plays. The computer can play a mirror image of the music played by the pianist; it can utter prerecorded sequences at times, tempos and intensities that follow the playing of the pianist; it can produce arpeggios at speeds depending upon the tempo of the pianist or upon the dynamics—piano or forte—of the pianist's performance. Thus the competent gestures of the performer influence the music and its performance in novel and unconventional ways. Several articles I have published elsewhere [14–19] present more detailed discussions of *Duets*.

CODA

While the scientist seeks knowledge, the artist, like the engineer, seeks action. Yet art and science, while they are different ways of taking the world into account, produce complementary kinds of knowledge. Jacques Mandelbrojt has pointed out that art is more concerned with internal reality than is science and cannot rival science as a description of external reality [20]. Yet art's concerns, demands, theory and practice can stimulate science, and the artistic exploration of new media helps the scientific understanding of phenomenal reality. I have tried to stress this point in the case of music, which is probably closer to science than any other art. The man who wrote “Ostinato rigore,” Leonardo—an artist and adventurer of knowledge and knowhow—was also a gifted and skilled musician.

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