Fifty Years of Digital Sound for Music

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Abstract — **Fifty years ago, Max Mathews opened new territories for music as he implemented the first digital synthesis and the first digital recording of sound. This presentation illustrates some specific problems and possibilities of computer music, focusing on the perception of musical sound and reflecting the points of view of the author.**

I. BEGINNINGS

Greece is the country of many beginnings. Democracy and philosophy were born here. So was mathematics, thus it is quite appropriate to hold here the 4th Sound and Music Computer Conference SMC'07. It is a great pleasure for me to speak in the beautiful island of Lefkada at the invitation of Anastasia Georgaki.

Fifty years ago, another beginning with far-reaching consequences took place at Bell Telephone Laboratories: Max Mathews realized the first digital synthesis and the first digital recording of sound. I wish to dedicate my presentation to Max, who opened new musical territories for music: not only did he give birth to computer music, but he carefully nurtured it with his inventive imagination and his exceptional scientific and technical talents. He generously helped musicians and institutions to have access to digital possibilities that could have long been confined to the leading scientific laboratories. His vision and guidance has proved invaluable to the field.

Whether apollonian or dionysian, music is a gift of the muses, and we are reminded that the main topics of computer music are reflected in the archetypes of three primordial muses: Melete for research; Mneme for memory; and Aidos, for voice and music making. According to Hugues Dufourt, one can distinguish two archetypes of musical sound: the voice, which needs to be sustained and attended to throughout its duration (so are the sounds of string or wind instruments), and the percussion, where the sound is left to decay unattended, so that the performer can immediately trigger other sounds (this is also true for the lyra, the guitar, the piano). In 1977, for the inauguration of IRCAM, Luciano Berio presented an audio-visual work illustrating electronic and computer music, "La voix des voies" (the voice of the channels). He distinguished three musical circles surrounding man: the voice, the most intimate source of the sound, from within the body; the musical instruments, exterior machines, but with direct bodily control of the sound; and the electroacoustic or computer sound, implying complex technical and logical mediations between the body and the sound.

I shall concentrate on some research points relating to my own music making; before that, I shall give a brief overview of developments over fifty years, and I shall evoke the problems of conservation and indexing. After my presentation, we shall hear Johan Sundberg, the great pionneer of singing voice and its synthesis – a great tribute to Aoidos.

II. DEVELOPMENTS OF COMPUTER MUSIC

Computer sound and computer music initially grew in relative isolation, with little consideration from the main stream of computer science and computer industry. As long as they were at Bell Labs, Max Mathews and John Pierce maintained an activity in computer music, even though speech research was more in line with the Bell management. This was also the case at M.I.T., where Barry Vercoe managed to keep fruitful musical developments going. John Chowning initially inconspicuously "sneaked in" his own computer music project within the Stanford Artificial Intelligence Laboratory headed by John McCarthy and mostly financed by NASA. Some American Universities – Columbia-Princeton, Queens College, Brooklyn Polytechnic, University of New Hampshire, Dartmouth College, Argonne National Laboratory, Oberlin College, McGill University – managed to get some computer music going, with the courageous efforts of people such as Geoffrey Winham, Jim Randall, Hubert Howe, Jon Appleton, Charles Dodge, Arthur Roberts, John Clough and others.

For more that thirty years it was a hard challenge to set up a computer music system in a musical environment. It is only around 1970 that digital sound made its way to other continents besides North America. The computer music scene gradually became active in Europe, with the Stockholm Electronic Music Studio, the Orsay Institut d'Electronique Fondamentale which I set up with Gérard Charbonneau, the Utrecht Centre directed by Göttfried-Michael Koenig, the D-A converter built by CNET for Iannis Xenakis, the Marseille-Luminy-CNRS project of Informatique Musicale, with Daniel Arfib and myself, and the development of IRCAM in Paris – the first large scale computer-based musical center. GRM, the birth place of musique concrète, also went digital, logically focusing on sound processing rather than sound synthesis. In England, Peter Zinovieff went from electronic to digital; composers such as Denis Smalley, Simon Emmerson and Trevor Wishart cooperated in "The Composer's Desktop project" to make computer music accessible to composers – this idea survives in the Sonic Arts Network. In America, Chowning started CCRMA – Computer Center for Research in Music and Acoustics - and other centers developed such as the Computer Music Experiment in San Diego. Real-time systems appeared – first hybrid, like GROOVE, designed by Max Mathews and F. Richard Moore, or others developed by Peter Zinovieff or Gustav Ciamaga ; later entirely digital, with a computer controlling a digital synthesizer : New England Digital's Synclavier, Hal Alles' Portable Digital

Sound System (Bell Laboratories) and Peppino di Giugno’s 4A, 4B, 4C, 4X machines (IRCAM, Paris). Ed Kobrin, Jon Appleton and some others hit the road with digital instruments. Joel Chadabe pioneered gesture-controlled composition, using a Theremin antenna interfaced with a Synclavier digital synthesizer.

In the 80s, the industry was effective in designing the MIDI format for digital exchange of musical information and the compact disk as a medium for digitally-recorded sound. It was only around 1987 that a commercial computer (the NeXT computer) was equipped with a good quality digital-to-analog converter.

Since then, computers have gradually become very powerful and relatively inexpensive, and a number of companies or individuals have developed musical software, so that individual composers can own their own music studio. As Max Mathews remarks, the power and speed of computers has increased by a factor of many thousands since 1957, and a laptop can now generate in real-time hundred of independent voices, so that one can no longer blame deficiencies in digital sound to insufficient complexity. One does not yet know enough about the specific features which make sound appealing to the listener’s ear and brain.

Research goes on in a number of centers – in Switzerland, Italy, Spain, Germany, Hungary, Portugal, Greece ... A great variety of music software became available, originating either from those centers or from private companies. It seems that most of the research and the available software relates to sound synthesis, processing and real-time performance. However music is composed and substantial research has been performed for many years on computer-assisted composition as well as on music analysis. It is somewhat artificial to separate composition from sonic processes, syntax from vocabulary. Varèse reminded that new materials allow and demand novel architectures. The computer permits to apply compositional processes at the microstructural level, to compose sounds themselves. This preoccupation has long been present in synthesis; it is reflected in the development of granular synthesis and in the merging of programs such as Open Music and MaxMSP. About ten years after the birth of *Organised Sound*, I salute the first issue of the *Journal of Mathematics and Music*.

Recently, the booming development of the world-wide web has made possible the down- loading of digital images and sound: the distribution of digitally-recorded music– « songs » has become a most profitable resource for the computer industry. Research on distributed computing has included sharing resources for computer music over the web – and one can buy expensive sampled sounds.

An intriguing emerging field is “Web musicking”- the idea is perhaps more exciting than the results. In November 1992, Michel Redolfi organized a “Transatlantic concert”, setting a MIDI satellite link between the Modern Art Museum in Nice and the Electronic Cafe in Los Angeles. Terry Riley, Michel Pascal and I myself performed on a Disklavier mechanized piano in Nice, which controlled the operation of a Disklavier in Los Angeles; David Rosenboom and Morton Subotnick performed in Los Angeles, controlling the Disklavier in Nice. Then David Rosenboom and Terry Riley improvised together ... but they heard their partner with an asymetrical delay of about a quarter of a second. Lately Chris Chafe and Michael Gurevitch of CCRMA studied the effect of time delay on ensemble accuracy, which has implication for networked musical performance: they claim that sensitive ensemble performance can be supported over long paths – say San Francisco to Denver – but not the world over. The earth is perhaps too big, or the speed of light is too slow – until we can master quantum effects of instant propagation.

Most music heard today comes from loudspeakers: it is stored and distributed in digital form. Technologies are changing very quickly, and recordings must be transferred from one recording medium to another to survive – “music for tape” is now stored as CD, CD-R or hard disks. The conservation of musical works which depend on a real-time performance by a digital system poses more difficult problems: many such works written to be performed live can now only be heard as recordings. To make it easier to port interactive pieces on newer systems, one must endeavor to specify the processes involved in a fairly general way rather than in terms of a particular device – the latter description is likely to soon become useless. The demands of digital coding are so specific and problems of compatibility are so acute that it is legitimate to question the reliability of digital archives.

At the same time, readable digital archives are extremely convenient for research, retrieval and analysis. A lot of work is carried on sound indexing and imaging. Mneme has gone digital with a huge and highly selective memory – but a very fragile one, seemingly better protected against deterioration but prone to vanish easily.

III. MUSICAL ISSUES OF COMPUTING SOUNDS

In the fifties, *musique concrète* was based on the editing of recorded sound objects, whereas *electronic music* was built up from electronically produced sound material. It seemed to me that although musique concrète was opening the scope of musical sounds, it did not provide the composer with the refined compositional control he or she could exert when writing instrumental music. The possibilities of transforming sounds are rudimentary in comparison to the richness and the variety of the available sounds, so that it is hard to avoid aesthetics of collage. In contradistinction, the sounds of electronic music could be controlled more precisely, but they were simplistic and dull, so that one was tempted to enrich them by complex manipulations, thus destroying the effectiveness of control one could have over them.

This conclusion prompted me in the sixties to explore the possibilities of computer sound synthesis. I felt that the precision and the reproducibility of the computer could help - while I always found something limited, contrived and whimsical about analog electronics. Synthesis permits to “compose” sounds in great detail.

The sound material thus obtained is highly ductile, and I hoped it could be made complex enough to be musically interesting, while too simple sounds can turn off demanding listeners.

IV. THE PSYCHOACOUSTIC PROBLEM

The most general method to produce sound is direct digital synthesis, implemented by Max Mathews as early as 1957: the computer directly computes the numbers representing the waveform. Thanks to the flexibility of programming, it can thus produce virtually any waveform, without having to build an actual vibrating system.

To avoid rewriting a new program for each sound, Mathews has designed convenient modular music compilers such as MusicIII, MusicIV and MusicV, which enable the user to produce a wide variety of sounds, simple or complex. The user has to specify to the program the physical structure of the desired sounds. This specification - the computer "score" - must be made according to specific conventions, which in effect define a language for sound description. A given MUSIC V score is thus a recipe requested by the computer to cook up the sounds and at the same time a thorough description of these sounds, which may be usefully communicated to other users.

One can thus manufacture sounds with unprecedented reproducibility and precision. This precision permits to achieve useful effects – which are sometimes not at all what one would expect from the recipe of the synthetic sound. The first attempts to use direct digital synthesis for music were disappointing. The early synthetic sounds lacked variety, richness and identity. One could not get exciting new sounds by varying parameters haphazardly.

Clearly, one lacked adequate physical descriptions of desired or interesting timbres. This is what we call the psychoacoustic problem: to use sound synthesis effectively, one must resort to some psychoacoustic knowledge or know-how on the relation between the physical structure - which the composer controls when he specifies the synthesis data - and the aural effect - which determines the musical impact. This was already a subject of polemics in ancient Greece: according to Pythagoras, numbers rule the world – the celestial harmony of planets, the *music of spheres*, as well as the harmony of music sounds. However Aristoxenus “the musician” disagreed, insisting that the justification of music is in the ear of the listener rather than in a mathematic rationale.

“Classical” western psychoacoustics developed by Helmholtz and Ohm is of little help here, since it bears mostly on the perception of simple sounds in isolation, while music deals with rich sounds in context. And the early synthesis attempts soon revealed that auditory perception has intricate and apparently whimsical features.

Clearly, one needed navigational advice to wander in the ocean of synthetic sounds that could afford a continuum of timbres – less familiar than a few typical instrumental prototypes similar to the islands of an archipelago. Think of the return of Odysseus, alias Ulysses: moving in the open sea of sound is adventurous – it can bring pleasant surprises, but also dangers and disappointments.

V. DISSEMINATING KNOW-HOW

Fortunately, the exploration of the musical possibilities of digital synthesis has much contributed to the growth of such psychoacoustic knowledge and know-how, and it has helped a lot to disseminate this know-how. After working several years to develop the possibilities of synthesis, I assembled in 1969 a "catalog of computer-synthesized sounds" (1969) to communicate the finds of my own research -a compilation requested by Max Mathews for a computer music course he gave in 1969 with John Chowning at Stanford University. This document provided a recording for a number of sounds or musical fragments, together with the MUSIC V "scores" written to obtain them. The scores permitted to replicate the synthesis - they also afforded a thorough description of the physical structure of the sounds. Additional explanations were given on both the production process and the musical context. Thus the sounds couls be replicated with MUSIC V, but also with other programs or other sound production processes. Most of the data I mention below on the imitation of instruments, the development of sonic processes or the creation of auditory paradoxes and illusions, can be found in the document in enough detail to replicate the examples today - or to produce variants from these examples. Other similar documents have proved useful (Cf. Risset & Mathews, 1969, Chowning, 1973, Mathews & Pierce, 1989, Boulanger, 2000).

VI. PERCEPTION IS SPECIFIC, NOT ARBITRARY

Auditory perception of musical sound has features that can appear strange and whimsical, but it is by no means arbitrary. Hearing has developed as an idiosyncratic process. The senses are not parameter-measuring devices: rather, they have specific ways to interpret the sensory signals so as to get useful information about the outside world - the issue is survival. Hearing can thus make subtle inferences to interpret a sound signal in terms of its acoustic production: however it is often at a loss with electrical sound signals which escape acoustic constrainsts (Cf. Risset, 1988, Bregman, 1990). To identify a source, the ear relies on subtle and elaborate cues, such that the identification can resist the distorsions occuring along the propagation of the sound signal.

VII. IMITATION OF INSTRUMENTS

Even familiar sounds, such as those of musical instruments, are harder to imitate than one initially expected. In particular, brass and bowed string instruments fiercely resisted imitative synthesis. Evidently, the cues for the recognition of these instruments were not as simple as one thought. Thus, in the early sixties, Mathews and I decided to embark on some research on imitating those sounds - not to provide ersatz, but rather to get insight on what determines the richness and the identity of violin or trumpet sounds.

The methodology we used can be called *analysis by synthesis*. The classical descriptions of instrumental sounds model them in terms of a characteristic fixed spectrum modulated by an amplitude envelope. The initial attempts to imitate brasses or strings with such a model failed completely, showing that the model is inadequate. In fact, using this model, electronic music had not succeeded in the fifties to properly imitate instrumental sounds.

We analyzed recorded tones, using protocols yielding the evolution of frequency spectra over time rather than a single, average spectrum. The time-varying analysis of trumpet sounds showed that the spectrum was variable throughout each tone. In particular, during the attack, the low-order harmonics reached their final amplitude earlier than the high-order ones. On hearing the attack, the ear cannot analyze what happens, it is not aware of this asynchrony, which occurs over some 30 milliseconds: but it recognizes it as a characteristic cue of a brassy attack, as synthesis tests demonstrate. Indeed, good simulations of the original tones could be achieved by modeling the sounds as a sum of harmonics, each of which endowed with its own envelope. The complex envelopes drawn from the analysis of actual brass sounds can be vastly simplified: however, a considerable amount of data is still required - especially since a new set of envelopes is required for tones of different pitches or different loudness. Clearly, it is valuable to try to characterize the timbre in a more compact way. I found that brassy tones could be characterized by a rather simple property: the higher the amplitude, the richer the spectrum in high order harmonics. In particular, this ensures the asynchrony of the harmonics during the attack. This insight permitted me to synthesize brassy tones “by rule”, the amplitude of each harmonic being deduced automatically from the envelope for the first harmonic.

I have dwelt at length with the case of my analysis by synthesis of brassy tones because it had several implications. It made it possible to produce brassy sounds with analog synthesizers: the property can be implemented thanks to filters with voltage-controlled bandwidth. But the most elegant implementation came later with John Chowning's frequency modulation: the modulation index, which determines the frequency bandwidth, can be made to follow the envelope. Synthesis experiments also show the importance of a wealth of specific details, sonic "accidents" or idiosyncrasies helping the ear to identify the origin of the sound. Even tuning characteristics can also affect what is called “timbre”.

Imitations of percussion instruments sound "synthetic" unless the decay times are different for different components - in general, longer for lower frequencies.

The strong identity of instrumental timbres can be an anchor, a point of departure for journeys throughout timbre space. With synthesis, one can compose the inner harmony of bell or gong-like sounds. The ductility of synthesis permits to perform intimate transformations, such transitions between two timbres. Both acoustic and digitally-generated tones can be localized within multidimensional representation of timbres based not on physical parameters, but on subjective judgments about similarities between these tones. As David Wessel states, such representations could “serve as a kind of map that would provide navigational advice to the composer interested in structuring aspects of timbre.”

VIII. COMPOSITIONAL DEVELOPMENTS OF TEXTURES

Synthetic timbres can become functional: they constitute the musical material, but their specific intimate structure relates to harmony, it has implications over the syntax. A synthesis program like MUSIC V permits to control both the synthesis of sounds and their disposition: the user can thus merge vocabulary and syntax. Depending upon their harmonic relation and their behavior in time, the components can merge into a single sound entity or be perceived as a multiplicity of sounds.

Grammatical constraints such as the serial techniques are too arbitrary in the harmonic dimension. With synthesis, one can compose spectra and timbres just as musical chords, and one can attribute a harmonic function to timbre. There is a relation between the inner structure of an inharmonic tone and the privileged frequency intervals between transpositions of such tones: the octave, the fifth and the third are privileged for harmonic tones with component frequencies f, 2f, 3f, etc, but they can be highly dissonant intervals for certain inharmonic tones. The synthesis of sustained tones with arbitrary spectral content has made possible the composition of novel musical structures tailoring timbre to harmony and scale, as exemplified by John Chowning’s *Stria*.

IX. AUDITORY ILLUSIONS AND PARADOXES

By contriving the structure of synthetic sounds in order to take in account the specific idiosyncrasies of hearing, one can produce auditory illusions or sounds with paradoxical properties. Such paradoxes and illusions reveal the very stuff of our hearing, but they also permit to create musical, morphological or theatrical effects.

In his piece *Turenas* (1972), John Chowning demonstrates powerful illusions of sources moving along trajectories that the ear can follow with quasi-graphic precision – four loudspeakers can suffice to suggest a compelling illusory space within which sounds seem to fly around without material constraints. Chowning’s processes are abundantly used. Research also attempts to approximate sonic wavefront reconstruction (suggested by Huygens for light) or “holophony”.

I could generate tones that seem to get lower when one doubles the frequencies of their components (with components separated by stretched octaves) : in fact, for many inharmonic sounds, the listener is likely to experience pitch relations which do not correspond to transposition one would expect from frequency ratios such as 2/1 or 3/2. I have generalized Roger Shepard's *chromatic scale to heaven*, generating endlessly descending or ascending glissandi, or sounds which go down the scale yet ares higher in pitch at the end than where they started (or vice-versa). This is the auditory counterpart of Escher's *Cascade*, where a stream appears to flow down ... to a higher point. Here I contrived the parameters so as to create a conflict between two aspects of pitch - tonal pitch and spectral pitch. While all components increase in frequency, the amplitudes of the higher components gradually increase to the prejudice of the lower ones: the center of gravity of the spectrum moves in a direction contrary to the motions of the components. The MusicV score can be found in my 1969 Catalog. The brevity of the score shows that even peculiar sound structures, where sounds are contrived in a most unnatural way, can be specified rather simply. Similar paradoxes can be demonstrated for rhythms, as demonstrated by Kenneth Knowlton and myself.

With digital tools, one can thus suggest an imagined, illusory world, a separate, internal sonic reality – which is embodied in real sounds without a material counterpart: it is exciting also to stage close encounters (of the third kind, with physical contact) between these immaterial sounds and acoustic sounds, audible traces of a visible world.

Illusions, “errors of the senses “, are “truths of perception “, according to Purkinje. Evolution has equipped the hearing sense with refined mechanisms for “auditory scene analysis” (Bregman, 1990): hearing is very good at taking in account the properties of sound generation and propagation in order to extract information on the environment. These skills are lost when the sounds are not produced in a mechanical world – this is the case of computer synthesis. This justifies the physical model approach, advocated by Claude Cadoz at ACROE, which also permits to develop visual and tactile counterparts to the synthetic sound world. This approach has been revisited by Max Mathews and Bill Verplank in their recent “scanning synthesis” method, which causes the sound wave to change at *haptic* frequencies – frequencies that could be produced by bodily motions. Mathews suggests that the motions of the articulators producing speech could be exploited more in music – some can be heard in François Bayle’s *Erosphere*. Similar to physical modelling, the waveguide approach suggested by Karplus and Strong and developed by Julius Smith, David Jaffe, Perry Cook and Scott Van Duyne is quite powerful.

X. INTIMATE TRANSFORMATIONS OF DIGITIZED SOUND

Synthesized sonic material is highly ductile and susceptible of intimate transformations. However, it can be dull, “dead and embalmed”, as Varèse said, unless one takes care to animate sounds to inject life into them. Instead of doing synthesis, one can take advantage of live sounds and process them by computer to tailor them to compositional needs.

Digital filters can transform in useful ways both the spectral and temporal behavior of sounds. According to Bilsen (1968), an early example of comb filtering was discovered in antique Greece: in an amphitheater facing the sea, one could hear a colored, pitched echo of sea sounds reflected from the steps : each step reflection added a precisely defined time delay, and the amount of coloration increases with the number of steps.

It is not easy to transform natural sounds with the flexibility and the ductility available in synthesis. A frequency transposition of a recorded motive will also change the tempo of the motive and shift the spectra of the sounds. Advanced techniques of signal processing are needed to perform intimate transformations upon recorded sounds. These techniques implement a so-called *analysis-synthesis* process: they decompose the signal into elements that can then be assembled together to reconstitute the original sound. Between analysis and synthesis, the data can be modified so as to transform the sound. For instance, if the analysis permits to separate parameters corresponding to an excitation and a response, these parameters can be modified independently. One can then change the speed of articulation of a recorded spoken voice by a large factor without altering the timbre or the intelligibility. This has been demonstrated using several signal processing techniques such as linear predictive coding or phase vocoder. Such techniques also allow producing sound “hybrids” via cross-synthesis: from two sounds, cross-synthesis creates a final sound which retains certain characteristics of both sounds. For instance one sound can imprint its frequency content and the other its dynamic contour over the final sound. I have made musical uses of these techniques in pieces such as *Sud* and *Elementa.*

The first accurate analysis-synthesis reconstruction of sounds in terms of Gabor grains and Gabor-like wavelets were performed by Daniel Arfib and Richard Kronland (cf. De Poli & al., 1991).In some sense, granular techniques, suggested by Gabor and Xenakis, introduced by Curtis Roads and Barry Truax and used by Horacio Vaggione, bridge synthesis and processing.

XI. REAL-TIME PERFORMANCE INTERACTION

In the 80s, Barry Vercoe, working initially with Larry Beauregard at IRCAM, then in M.I.T., has implemented a process whereby a computer program followed the score played by a performer, so that a *synthetic performer* can accompany the live performer. This was used in works by Philippe Manoury, Cort Lippe and many others. Miller Puckette developed to this end a remarkable graphic programming environment, Max, later amplified into MaxMSP, a real-time modular program with advanced scheduling capabilities for both synthesis and programming. Roger Dannenberg also developed interactive software. Interaction can resort to various devices to capture gestures, such as Max Mathews’ radio baton, Don Buchla’s Thunder and Lightning, David Wessel and Adrian Freed’s work on sensitive material. Daniel Arfib and his students have explored the important issue of mapping the gesture parameters to various aspects of the sound.

Invited in 1989 as composer in residence in the Music and Cognition Group, Media Laboratory, M.I.T., I realized a *duet for one pianist*, to my knowledge the first example of real-time programmed interaction in a purely acoustic world. In addition to the pianist's part, a second part is played on the same piano - an acoustic piano, with keys, strings and hammers - by a computer which follows the pianist's performance. This requires a special piano - here a Yamaha Disklavier. On this piano, each key can be played from the keyboard, but it can also be activated by external electrical signals: these signals trigger motors which actually depress or release the keys. Each key also sends out information as to when and how loud it is played. The information to and from the piano is in the MIDI format. A Macintosh computer receives this information and sends back the appropriate signals to trigger the piano playing: the programming specifies in what way the computer part depends upon what the pianist plays. In each piece a different kind of interaction is implemented. This novel interaction was implemented in MAX with the most dedicated and competent help of Scott Van Duyne. After realizing eight *Sketches*, I wrote three *Etudes: Echo, Narcissus, Mercury*. Greek archetypes are irresistible!

Clearly, this process can merge composition and performance: compositional rules can be programmed and made sensitive to the way the piano is played. For instance, the tempo or the harmony of the added part could be determined by the loudness of the performance. Although the process lends itself very well to improvisation, I have not used it myself in this context.

XII. CODA

The computer is invaluable as a workshop to design and build tools which are material as well as intellectual. Using the computer helps to bridge gaps between various aspects of music making: acoustic and synthetic sound material; real-time and delayed synthesis; synthesis and processing of sound; music composition, sound production and performance.

I believe that the field of computer music is complex enough to be chaotic, so I shall not attempt to predict the future. I have emphasized certain past developments that appear to me to be very specific of computer music and very significant, so this was a partial and subjective review reflecting my own biases and interests. I shall conclude by wishful thoughts - a reminder, a caveat and a plea.

Let us not forget that the aesthetic value of the music is by no means guaranteed by the scientific or technical apparatus it resorts to. Computer music should be evaluated as music, not as experiment – composing remains an individual venture, for which responsibility and artistic commitment rest upon the author.

Max Mathews reminds us that if any sound the human ear can hear can be made from samples, most sounds are ugly, unpleasant, not interesting, painful or dangerous. We only have two ears, which are are extremely sensitive and delicate. Electronic amplification of sounds can reach harmful levels, and auditory traumas are too often caused by long exposure to loud electroacoustic sounds or by unexpected sudden increases in loudness. Electronic amplification of sounds can reach harmful levels, and resorting to excessive intensity is a wrong way to endow sounds endowed with energy. When we listen to a brassy sound over the radio, we still hear whether the performer plays f or p regardless of the amplification: one should beware of abusing listeners and deafening them with decibels. Subtler cues can suggest lively sounds with energy at the source.

Today there is a strong pressure for big and fast profits. But the music reaching the biggest and fastest commercial success rarely has lasting value: it generally soon gets worn out. Marketing-based music – which implies huge publicity expenses – relies on recipes that are quickly exhausted. The most original creations are usually not appreciated immediately, and the present urge for immediate satisfaction and fast return on investment carries a great danger of killing the golden-egg hen. The field of computer music was mostly developed by persons longing for innovative and demanding music – looking for new materials and new architectures. I plea for the continuation of this quest – harder but rewarding – and I am confident that curiosity and creativity will continue to animate our collectivity.

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