SYNTHESIS OF SOUNDS BY COMPUTER AND PROBLEMS CONCERNING TIMBRE

by

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BY means of appropriate programs, the numerical synthesis of sounds by computers provides the possibility of synthesizing practically any sound whatsoever starting out with a description of its physical structure.

In order to make the most of the immense resources available, the musician must know which parameters to specify so as to obtain any desired sound. The process of sound synthesis by computer therefore involves an understanding of the fundamental problem of electroacoustical music : the relationship between the physical parameters and the perceivable characteristics of sounds — which might be referred to as the problem of timbres (as in the title of the present article).

After having succinctly explained the synthesis process, I intend to describe certain sounds that can only be obtained by means of this process — these sounds point out the inadequacy of classical notions concerning the relationships between frequency on the one hand and perceived pitch and timbre on the other. Then I shall demonstrate that the synthesis process constitutes a precious tool for helping in the development of the science of correlations between physical structure and the perceived aspects of sounds ; it provides a sound method for the study of traditional instrumental sounds, and it permits the exploration of the subjective rôle of physical parameters of various sounds, at the same time making it easy for the research workers and musicians engaged upon such tasks to communicate the results of their investigations.

TECHNICAL DESCRIPTION OF THE NUMERICAL SYNTHESIS OF SOUNDS

A computer processes numbers. By means of numerical-analog converters, these numbers can be transformed into electrical tensions that are proportional

to the numbers. The computer can be given the job of supplying the sound wave — or at least an approximation of it — through programming the computation of successive *values* sufficiently close to the amplitude of the wave... which are called *samples* of the wave (1).

The sound wave is defined by the function p(t), giving the acoustic pressure as a function of time; p(t) is proportional to the variable electrical tension that must be sent to a loudspeaker in order to produce the sound. Starting out with these successive numbers, the function p(t) can be built up; the numbers are transformed into electrical pulses of proportional amplitude by means of a numerical-analog converter, then these pulses are smoothed; an appropriate low-pass filter makes use of these pulses in order to send out a continuously variable electrical tension, and the sound is produced by branching this tension to the terminals of a loudspeaker. Obviously the sound can be recorded on tape.

It is intuitively conceivable that a rapidly varying wave function p(t) requires a greater supply of numbers. Mathematically, if frequencies up to a maximum of f are required, then it is necessary (and also sufficient) to have at least 2f samples per second. So, to obtain a bandwidth of 20,000 cycles per second, 40,000 numbers must be specified for each second of sound.

It is obvious that such a process would be out of the question if it were not for the rapidity and patience of computers. The time needed for computing the samples depends on the computer used, as well as the program and the complexity of the sounds. Normally it is not possible to work in real time; that is, the computer takes longer than 10 seconds, for example, to compute the samples required for 10 seconds of sound. So the work is usually carried out in two stages. In the initial phase the computer calculates the sample values and writes the obtained series of numbers on to a digital magnetic tape. During a second phase, these numbers that have been previously written on to tape are read out at a perfectly regular rhythm (of 2f numbers per second) and fed into the converter. This second phase requires equipment that, up until now, has only been available in the U.S.A., although it presents no particular technical difficulties (similar equipment will soon be put into use in Europe).

The technical limitations of the process are determined by the necessity of replacing continuous quantities by discrete numbers, which is an obligatory characteristic of all computer processing. But by means of sufficiently minute quantifications, these limitations can be reduced to a point that lies beyond the distinctions that are detected by the human ear, or beyond the distorsions introduced by the use of sound reproduction equipment. (In representing the samples by four significant figures, the signal-to-noise ratio is greater than

(1) M. V. Mathews, « The Technology of Computer Music », M. I. T. Press, Cambridge, Mass., U. S. A. (1969).

70 dB; a sampling rate of 50,000 samples per second permits frequencies up to 25,000 cycles per second.)

The process makes it possible to obtain stereo output on two, three or four channels (or even more); in such cases the computer outputs the corresponding number of independent and synchronized sample sequences.

The numerical synthesis of sounds by computation of samples of the sound wave is undoubtedly the only means of deriving benefit from the computer's characteristic universality. The computer can also be employed for the control of an external sound synthesizer; this has been done by Gabura and Ciamaga at the University of Toronto, Mathews and Moore at Bell Telephone Laboratories, and Zinovieff at the Electronic Music Studio in London; this is what Knut Wiggen will be doing in the near future at the Stockholm studio. Such a method is less demanding on the computer, and makes it possible to work in real time; however the sounds obtained are unfortunately limited, both in quantity and quality, by the available external equipment.

In order to make use of digital sound synthesis, the computer must be taught to compute the series of sample values that correspond to the desired sound. The computer requires a program in order to work, and such a program must be written in an artificial language, and must unambiguously specify the steps to be carried out, and the operations to be performed. If a new program had to be written for each new sound, then the process would be slow and difficult to use... and it would certainly frighten off many musicians who have neither the possibility nor the desire to work as programmers. Max Mathews, the pioneer in computer-assisted sound synthesis, got around this problem by the development of a software that is easy to use, and that enables the musician to turn out an enormous range of sounds. The programs that make up this software are now available, and can be easily implemented on various different computers. This is the only software that is widely used at present for the synthesis of musical sounds. I now intend to describe this software, and to point out both the possibilities of the process as well as the problems that it presents.

MUSIC V : A GENERAL SOFTWARE FOR SOUND SYNTHESIS

MUSIC V is the name of the latest version of a series of programs designed by Mathews at the Bell Telephone Laboratories between 1958 and 1967. These programs attempt to reconcile the sometimes contradictory requirements with which a useful sound synthesis software must cope. Such a software must remain sufficiently general, and must not impose too many restrictions upon the sounds that can be obtained from it. It should be simple to use, and it should permit the easy specification of single complex sounds or of series of complex sounds. Finally this software should be efficient, and should not require considerable computing time.

In MUSIC V, efficiency is brought about by the use of certain methods (particularly table look-ups carried out on functions that have been previously stored in memory) which will not be described in the present paper. Because of the matters to be treated later on in this paper, it will be useful now to propose various ideas concerning the language itself, specifically designed for the MUSIC V software, in which the user describes the sounds which he asks the computer to synthesize.

The user of MUSIC V controls the level of complexity that he wants to achieve concerning the physical structure of his sounds. This description is usually « macroscopic », that is, the user describes either the large-scale parameters of his sounds, or their temporal evolution... but not the individual sample values (it is the MUSIC V software which carries out these « microscopic » computations, making use of the « macroscopic » description provided by the user). Moreover the user has the possibility of combining, in any desired manner, various functional blocks — represented by groups of instructions designed to carry out a specific function. These functional blocks enable the user to simulate the effect, for example, of an oscillator, or a channel mixer, or a noise generator. The user provides an initial definition — or « declaration » — specifying which blocks he intends to use, and how they are to be connected. Each block assembly is called an « instrument ». The components in a instrument determine what sort of *computations* are to be carried out in order to produce the set of sample values representing the instrument's sounds; however once an instrument is initially defined in this way, the musician still has to specify how he would like to *use* this instrument, that is, the exact *input parameters* that he intends to supply to the instrument. For example, imagine an instrument that represents a simple oscillator; it will therefore produce periodic sounds, and the user must specify the starting time of these sounds, their duration, their amplitude, their frequency, and their waveform. For more complex instruments the range of parameters — and therefore the range of possible sounds — is much more extensive. In choosing his « instruments », the user determines a level of complexity falling between two extreme limits : on the one hand, the level of extreme *simplicity*, at which restrictions are placed upon the available sounds; and on the other hand, the level of extreme *generality*, which requires a great deal of preparatory work.

Having defined the set of instruments to be used, the MUSIC V user has to write instructions in order to activate these various instruments : these instructions specify, for each sonic event, the starting point, the duration, the reference number of the instrument to be used, and the other various input parameters required by that instrument. By analogy the term « notes » is used to describe these instructions. Although the notes employed by MUSIC V do in fact correspond to the notes of a classical music score, they can also correspond to sonic events which last for either one millisecond or, for example, ten minutes. As can be seen, the note concept in MUSIC V is

equivalent to describing sound in terms of simple or complex sonic events having a certain starting point and a certain duration, each of these events being produced by an « instrument ». These sonic events can of course be superimposed in any desired manner : that is, different instruments can be played at the same time, and each instrument can produce several simultaneous voices.

As a result of the modifiable design of the functional blocks, and the diversity of functions that can be brought into use, MUSIC V permits the production of sounds corresponding to an extensive variety of physical parameters. It is difficult to imagine any physical sound structures which might fall beyond the scope of MUSIC V (possibly modified or completed), at least insofar as obtaining an approximation of that sound is concerned, and no matter whether these sounds are random, quasi-periodic, or whether they evolve according to complex laws. At one and the same time, therefore, MUSIC V provides a language for defining the « score », the set of « instruments » and the « notes » ; such a « score » provides a total description of the information required to create sounds, which means, in more simple terms, that the « score » represents an unambiguous definition of the physical structure of these sounds.

Therefore a software such as MUSIC V solves the sound synthesis problem by making use of data concerning the physical parameters of sound ; the written « score » used for creating sounds is at the same time a description of the physical structure of these sounds.

« PARADOXAL » SOUNDS OBTAINED BY MEANS OF MUSIC V : FREQUENCY AND PITCH

Because of the control of sonic parameters which it permits, MUSIC V makes it possible to synthesize very artificial sounds revealing paradoxal properties. R.N. Shepard has synthesized twelve sounds which form the degrees of a chromatic scale, and which give the impression of ascending indefinitely whenever the scale is repeated (2). I went on to generalize this paradox by synthesizing other sounds : glissandi which ascend or descend indefinitely ; series of periodic sounds whose pitch descends, but for which the pitch of the final sound is nevertheless higher than that of the initial sound in the series ; sounds which descend the scale while becoming gradually higher pitched ; and a sound whose pitch is lowered whenever the frequencies of its components are all doubled, as for example when you double the tape speed of the recorder

(2) R. N. SHEPARD, « Circularity in Judgements of Relative Pitch », J. Acoust. Soc. Am. *36* (1964), p. 2346.

on which it is being played (3). These sounds, obtained by means of MUSIC V, would have been impossible or very difficult to obtain by other means than digital sound synthesis. The manner in which they are perceived contradicts currently accepted conceptions concerning the parallelism between pitch and frequency, but this manner of perception could well be interpreted within the context of a more elaborate theory of pitch perception.

Here is an outline of such a theory. One would start out by stipulating that the pitch attribute is composed of two elements : first, the « tone », which is the same for all sounds separated by octave intervals, and whose presence is implied by the fact that musicians give the same name to all the C's, all the D's, etc. ; second, the natural pitch, which enables us to distinguish a low note from a high note. The directions of variation of tone and of pitch are usually identical for sounds produced by « natural » sources ; for example, whenever a player ascends a scale on a musical instrument (that is, when he passes through the cycle of chromatic notes in the direction C, C-sharp, D, etc.), he goes from the *low* end to the *high* end ; tone and pitch both vary in such a way as to cause us to say : « the sound ascends ». However, for sounds formed by components at octave intervals, tone is easy to recognize : it is the tone of any one of the components ; the pitch depends upon the spectrum, or the distribution of component amplitudes, which in this case goes beyond the coloration normally thought of as timbre ; the sound will in fact be higher when the high components are reinforced. With the help of MUSIC V, it is possible to independently control the component frequencies (which retain their octave relationships) and their spectral envelopes ; by lowering the component frequencies and by simultaneously moving the envelope towards the high frequencies, it becomes possible to separate tone and pitch attributes, which gives rise to the paradoxal situation of a scale which gets higher in pitch at the same time as it is descended. It is therefore the control obtained through digital sound synthesis which make it possible to show up apparent paradoxes, which open up new musical possibilities which could never have existed with traditional instruments.

THE PROBLEM OF THE RELATIONSHIP BETWEEN PHYSICAL PARAMETERS AND PERCEPTIBLE CHARACTERISTICS

By means of software such as MUSIC V, the computer permits sound synthesis to be carried out under remarkably controlled conditions, which are also precise and reproduceable ; synthetic sounds are entirely determined by a

(3) J. C. Risset, « Pitch Control and Pitch Paradoxes Demonstrated with Computer-Synthetized Sounds », J. Acoust. Soc. Am. *46* (1969), p. 88 (Abstract : detailed article to appear later).

description of their physical parameters. Now this raises a problem : the computer makes it possible to produce any sound whatsoever that can be described numerically, but then it is not always possible to numerically describe certain sounds, even though they are very familiar. The musician might have an exact idea of the type of sound he wants ; maybe he can describe it phenomenologically, by using adjectives, or maybe he refers to known instrumental sounds. The computer can do nothing with these sorts of descriptions, since it requires a complete physical description of the desired sounds. The machine needs the details which are implied when, for example, one speaks of a brass sound, without being able to translate this notion into physical parameters. Whenever a musician sets out upon synthesis experiments in an empirical manner, he is likely to be disappointed in the beginning ; even though the resources of the process are theoretically unlimited, his initial efforts lead only to sounds that have neither vitality nor prominent features. Several years ago, J.R. Pierce compared this situation with that of a « savage in front of a grand piano » : marvellous music could certainly be obtained from that instrument, but one needs to know how to play it.

So, in order to profit from the immense sound resources offered by the computer, it becomes necessary to develop a psychoacoustical science, involving a knowledge of the correlations between the physical parameters and the perceptible characteristics of sound. This is also the essential problem for electroacoustical music in general, since the composer is in direct contact with the physical aspects of sound, whereas he aims at controlling their perceptible aspects. However it is difficult to determine relationships between two fields which are so little known. Even though we know how to isolate physical parameters, it is not easy to come to precise terms with the perceptible characteristics of sounds. Pierre Schaeffer and the Musical Research Group in Paris have made very important contributions in this respect ; they have attempted to design a solfège for sonic objects, which opens out to provide a map of the perceptible domain, allowing the identification of any sonic object whatsoever in the space of perceived sounds (4). The Schaefferian solfège provides a « methodical background » which might plausibly be used as a guiding light in this sort of search for correlations. Nevertheless, just as a map is hardly sufficient for indicating the essential nature of an entire land, there is nothing to be gained from merely listing all the various types of sounds which might exist (5). Such a catalogue cannot be considered as a sufficiently subtle description for deducing a language which might be used for controlling the multiple resources introduced by computer sound synthesis. (It should be pointed out that a training in sonic morphology can in many cases be helpful in computer sound synthesis ; by means of manipulating recorded sounds one

(4) P. SCHAEFFER, « Traité des objets musicaux », Seuil, Paris (1966).
(5) See page 581 of Schaeffer's « Traité des objets musicaux ».

can obtain information concerning their form and their material content — called « matter » by Schaeffer — to such an extent that it becomes possible to re-create by synthesis sounds belonging to the same family.)

Supplementary features and further dimensions of sound perception can possibly be revealed by factor analysis methods (6) (7). The system of phenomenological description of sound will no doubt be refined, but maybe insufficiently. It will nevertheless become essential to achieve a sufficiently detailed separation of the zones of perceptional space, except that this would already appear to be beyond our capabilities. Timbre is an attribute whose dimensionality is too high, and besides, it is impossible to follow through this question of perceptible characteristics to its logical end without making reference to the musical context, and to the functional rôle of a sound within a more vast structure.

It is therefore impossible to study the correlations between physical parameters and perceptible characteristics in an entirely methodical manner in that we do not dispose of sufficiently detailed identifiers in the perceptional domain. However the synthesis of sounds by computer gives us solid control over the physical parameters. For each synthesis trial carried out, one knows (by construction, it might be said) the physical parameters of the sound — in the form of the « score » which is necessary for obtaining the sound by means of a software like MUSIC V. The same synthesis can of course be carried out in several years time, maybe on a different computer; these « scores » make it easy to set up sound libraries, and make it possible to transmit to other users, over a distance, a physical description which is also a recipe for obtaining the sounds in question. This makes it feasible to decipher little by little the effects of the various parameters in a sound, by modifying one by one the different parameters in the synthesized sound. The influence of these modifications upon timbre can then be evaluated by listening to the sounds produced, and each investigator is able to repeat such experiments in his own laboratory, with the eventual intention of establishing his own criteria of perception (using, if desired, the solfège breakdown proposed by Schaeffer, making use therefore of references to musical structures) on the basis of an exact layout concerning the physical parameters. If, as at present, numerous musicians use the same software, such as MUSIC V, which provides a descriptive language of the physical structure of sounds, each musician can then profit from the others as far as his own explorations are concerned. He has only to make up his mind to regularly publish the sounds obtained (on tape or disk) as well as a description of these sounds in MUSIC V language. In this manner

(6) J. P. Benzecri, « Analyse factorielle des proximités », published by the Statistics Institute of the University of Paris, Part I-13 (1964), Part II-14 (1965).

(7) R. N. Shepard and J. D. Craroll, « Parametric Representation of Nonlinear Data Structures », in : Multivariate Analysis, Academic Press, New York (1966), p. 561.

I myself published several results in a « catalogue » of synthetic sounds (8). This catalogue covers only a minute part of the domain to be explored, and it is reasonably imperfect, but it has already been of some use to musicians employing MUSIC V or analog sound synthesizers (9). The idea of a catalogue seems important; it enables composers of experimental music to accumulate their efforts without surrendering their differences.

Since it is necessary to completely specify the physical details of a sound — which constitutes the essential difficulty of the process — the possibilities of enrichment due to MUSIC V are irreversible; that is, once the sound is obtained, the musician also possesses both a physical description of the sound, as well as a recipe for reproducing it. The empirical investigations carried out in traditional electronic studios often lead to results which cannot be reproduced. Of course it is a restriction to use one software only, and MUSIC V, although very general, is hardly universal; however one should not neglect the opportunity of making use of a common reference language such as this : not only is it possible to carry out one's own experiments, but it is also possible to reach conclusions based upon the experimental work of others.

The digital synthesis of sounds by computer does not produce results immediately... above all if it is necessary to await one's turn in the long queues that exist at most computing centers, between successive synthesis trials. It is preferable to adapt the synthesis software to a smaller computer, used by one person at a time, and which also controls the conversion process. In this way, responses are more rapid, which leads to an acceleration in the improvement of sound synthesis procedures. Small and medium computers are becoming more and more widespread; they enable the user to come into closer contact with the synthesized sounds, above all with the arrival of graphic and manual input-output techniques. Furthermore, these smaller computers are relatively low-cost; in fact the cost of a small computer is roughly equivalent to the cost of a large electronic music studio.

It is important to mention here the various research projects which have already been carried out since the beginnings of computer sound synthesis. I would like to give two examples which seem to me very significant.

SOUND SYNTHESIS IMITATING MUSICAL INSTRUMENTS

Ever since Helmholtz, acoustics textbooks explain that timbre — the distinctive quality of a musical instrument — is associated with harmonic spectra; the configuration of a spectrum would then determine the timbre of

(8) J. C. RISSET, « An Introductory Catalogue of Computer Synthetized Sounds », Bell Telephone Laboratories, Murray Hill, N. J., U. S. A. (1969).

(9) M. V. MATHEWS, « The Electronic Sound Studio of the 1970's ». See page 129 of the present publication.

the instrument. The research work carried out by Schaeffer's group (4) pointed out the total inadequacy of such a simple conception, as did the studies carried out by the Musical Acoustics Group of E. Leipp (10) and the experiments of M. Clark (11) and his colleagues. Computer sound synthesis provides an immediate demonstration of the invalidity of the classical conception. If one uses the physical descriptions of instrumental sounds that are to be found in the textbooks, the sounds obtained generally have little connection with the instrumental sounds desired. It is therefore necessary to carry out more advanced analyses of the instrumental sounds; however the results vary considerably, and are complex, and in order to make use of these results it becomes necessary to retain only those features of the analysis which are pertinent to the human ear. Computer synthesis makes this possible.

The computer provides us with the tools of a feasible study method for musical instrument sounds (12). First of all we analyze recordings of real sounds, with the participation of the computer. By means of analog-digital conversion, samples of the sound wave are obtained, which can then be given over to analysis programs capable of providing precise and detailed data on the evolution of the sound. These complex analysis results are used to extract a series of physical parameters describing the instrument's sounds. We then synthesize sounds according to these parameters. Auditive tests make it possible to evaluate the similarity between the real and synthetic sounds, which indicates whether the chosen parameters are sufficient for describing the sounds. If this is not the case, then other analyses must be carried out, or else other parameters must be extracted from the analyses already performed. Finally we systematically modify the parameters of the synthetic sounds — one by one — in order to evaluate, by listening, the significance of the extracted parameters. This makes it possible to arrive at a model, which is a pertinent schema of the sounds of the instrument, and which enables us to carry out simplified syntheses.

Such a schema leaves out details and accidents. Schaeffer gave an example of one such schema with his « piano law » (13). Mathews has schematized the sound of stringed instruments (played *arco*) by a triangular wave which is modified — that is, filtered — by numerous resonances (more than ten), which explains the particular richness of the vibrato in such sounds, and which brings about a spectrum modulation as well as frequency modulation. I showed that the essential property of brass sounds is the dependence of spectra with respect to level; the proportion of high frequency energy increases greatly with intensity.

(10) Bulletins du Groupe d'Acoustique Musicale (1963-1970), Acoustics Laboratory of the Faculty of Science, 9, quai Saint-Bernard, Paris-5ᵉ.
(11) J. M. Clark, « Several Problems in Musical Acoustics », J. Audio Engineering Sty. 7 (1959), p. 2.
(12) J. C. Risset and M. V. Mathews, « Analysis of Musical Instrument Tones », Physics Today *22*, N° 2 (1969), p. 23.
(13) See page 234 of Schaeffer's « Traité des objets musicaux ».

Obviously, for the musician, the imitation of existing instrumental sounds does not represent the principal attraction of computer sound synthesis (although this might be the case for certain composers who seek simply to find a means of doing away with human performers). Nevertheless this imitation has an interest which is not purely academic. The repertory of available sounds would be incomplete if it did not include the families of instrumental sounds. As has been pointed out in the work carried out by Leipp (10), traditional instruments have passed their test, and their present form is the end-result of secular and empirical improvements which have tended to increase their interest and their « musical performance » ; in concentrating upon these instruments, one is likely to discover musically significant production processes. Insofar as the composer is familiar with the sounds of an instrumental type, he will inevitably find it simpler, in front of the computer, to make use of his previous musical conceptions and his science of orchestration. Finally the composer might wish to associate with the synthetic sound tape other sounds coming from live instruments, which might partly solve the problem of the fixity, from one performance to another, of tape music, and its not very spectacular nature. When the composer has the opportunity of using sounds which resemble those created by real instruments, he is in a position to bring about associations between sounds in a more homogeneous and less trivial manner, and can achieve certain subtle effects (responses, mirrors, transitions) between the timbres of different instruments... and can even extrapolate still further. The simulated instruments can be given new characteristics, as for example in the harmonic composition of a false gong sound. Of course it is nevertheless the possibility of the computer in proposing completely different sounds which remains the most fascinating aspect.

SONIC DEVELOPMENT : COMPOSITION AT THE SOUND LEVEL

The computer makes it possible to go beyond the note or sonic object considered as the necessary element of composition ; it makes it possible to develop sonic processes which might be thought of as authentic composition processes at the level of sounds. The limits in this domain are those due to the composer's lack of imagination.

I would like to mention, by way of an example, a procedure for harmonic development used in my piece « Mutations ». The mutation stops on an organ make harmonic addition possible. The computer can of course control harmonic addition in a very much more elaborate manner. The « spectral analysis » of a chord might be developed ; first of all only the fundamental component of the chord is presented, then the 2nd and then the 3rd harmonics ; when the 4th harmonic appears, the first can be eliminated, the 2nd eliminated when the 5th appears, and so on. This rise towards the superior harmonics can be

carried out at different rhythms for the different notes in the chord. The sonic development can be carried out in a more complex manner starting with a harmonic structure ; such a structure can be used to reveal a quantification of pitch space, and a natural scale more condensed in the high register than in the low. One might end up with sonic tissues for which harmonic development determines the melodic aspect as well as the timbre.

CONCLUSIONS

The digital synthesis of sounds by computer is hardly a justification for believing in mechanical miracles ; the use of a computer points out clearly the problems of timbre, and calls for an authentic programme of sonic and musical research on the part of those who wish to exploit the computer's virtual possibilities. In order to extend its resources, computer sound synthesis must make use of the methods and discoveries of other experimental musics ; but nevertheless computer sound synthesis can also provide considerable assistance in the exploration of timbre, because of its rigorous nature, because of its possibilities of reproduction, and finally because it makes it possible to define sound-description languages which are also operational instructions for the synthesis of these sounds.

This is the basis of the interest of catalogues listing computer-synthesized sounds, in which can be found both a description of the sounds in such a language together with a recording of these sounds, which provides an opportunity of communication between research workers and musicians interested in such sounds. The extension of such catalogues will help in determining the pertinent physical parameters — both from an auditive and a musical point of view — and will also help in defining the problem of the relationships between physical parameters and perceptible characteristics of sounds, which will in turn contribute towards the musical domination of the sonic universe.

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