Rapports IRCAM

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Research at IRCAM in 1977

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RESEARCH AT IRCAM IN 1977

Research at IRCAM in 1977 centered around sound synthesis using digital techniques. There were good reasons for this choice of orientation. Since the beginnings of electronic music some thirty years ago, composers have tried to gain control over the inner structure of sound, to compose sounds themselves, rather than merely with sounds. The use of electronic instruments to produce and transform sound seemed at first to offer this control; very soon however it became clear that the sounds produced either by measuring devices like tone generators, or by voltage-control devices such as in synthesizers, could not begin to match in complexity or subtlety even the simplest natural or instrumental sound. Clearly these kinds of sounds could be used to write music, but composers felt the need of more delicate and differentiated tools.

The computer offers such a tool. Its speed and precision make it an incomparable sound analyser, capable of sampling a signal at more than 30,000 times per second. After analysing a signal, one can process the numbers representing the results of the analysis and thus resynthesize the signal. By using other numbers one can synthesize a completely new sound.

It is the possibility of such intimate control at such small intervals of time which allows one to synthesize with the aid of the computer sounds of great complexity, particularly in regard to the temporal evolution of their spectra. A large part of IRCAM's research during the past year has been devoted to rendering this tool more easily usable by composers.

The research on digital sound synthesis has been carried out under three different aspects:

- Digital synthesis on general purpose computers,
- Digital synthesis on specific devices, and
- Psychoacoustic studies to aid synthesis.

Digital Synthesis on general purpose computers.

IRCAM has during the last year, devoted a great deal of energy to the development and extension of the sound synthesis program Music V developed at Bell Laboratories by Max Mathews and others. This extended Music V resides on a Digital Equipment Corporation PDP10 system. The system itself has 192,000 words of core memory, about 30 million words of disc storage and can be used by up to 16 people at a time.

This version of Music V is largely the work of John Gardner. It represents an extension of Music V in the following regards:

- Pass I and Pass II have been combined.
- The number of unit generators has been increased to 60, including a set of logical unit generators for the transfer of control on the basis of logical and arithmetic tests.
- The program now contains a parser which allows the composer to do conversion and complex mathematical evaluations and calculations directly within the instrument definition rather than having to write special subprograms or to make frequent use of the general conversion subprogram.
- There is dynamic memory allocation in Pass III, making unnecessary the restriction of the number of permissible output blocks.
- Some syntactic changes have been made, leaving this language compatible with Music V, but rendering it easier to use.

The following compositions were written at IRCAM during the past year using this sound synthesis system:

Michel Decoust: Interphone
Stanley Haynes: Prism
Jean-Claude Risset: Inharmoniques
Trois moments Newtoniens.

In addition to this system, a number of programs of sound analysis and transformation have been put into operation, many of them from the Computer Music Group of the Stanford Artificial Intelligence Laboratories:

- a program for the digital mixing and reverberation of sound;
- a program for the display and analysis of sound;
- a filter design program allowing the user to design filters of virtually any characteristics and to filter sound files;
- a set of programs for the analysis and synthesis of speech using linear predictive coding techniques;
- two programs of coded entry of information for sound synthesis, both producing note-lists for Music V, MUSICA by Giuseppe de Poli, a straightforward but very efficient language for encoding musical texts, and SCORE by Leland Smith, a more sophisticated entry language permitting the manipulation of entire motives and phrases to engender new phrases.

Finally, IRCAM has completed the design of new circuits for analog-to-digital and for digital-to-analog conversion with 16 bits of precision which will be built in the course of the spring of 1978 and subsequently installed on all the IRCAM computers.

Digital Synthesis on specific devices.

Digital sound synthesis on general purpose computers is a very rich tool for composers. It has the disadvantage of being time-consuming. To obtain digital synthesis in real time, G. Di Giugno, in 1976, designed and constructed a system (4A) which is now in use at IRCAM. It provides 256 oscillators, 256 amplitude modulators and the use of any wave form. Frequency, amplitude and phase are controlled by a mini-computer PDP 11/40. Up to four wave-shapes of 4000 words' resolution can be used simultaneously. Oscillator phase is calculated by a 24-bit accumulator giving a frequency resolution of $\simeq$.002 Hz. The phase is used to address the wave-shape table. The 14-bit wave-shape table output is multiplied by a 12-bit amplitude function; 24 bits of the product are retained.

To provide faster and more powerful possibilities, during the month of April 1977, H.G. Alles and G. Di Giugno developed another system (4B) which is also in use at IRCAM. It provides 64 FM oscillators and 15 accumulating registers for interconnection of the oscillators. It is directly interfaced to a Digital Equipment Corporation LS1-11 micro-computer. The control parameters of the synthesizer all appear in LS1-11 memory space and thus can be directly manipulated by any LS1-11 instruction. The oscillator frequency and amplitude values are generated by ramp processes that calculate new values at a 4 KHz rate.

G. Di Giugno has recently begun the construction of a more advanced prototype (4C) which will be ready by May 1978. The system is provided with 64 timers and more versatile and sophisticated interconnections. The envelope generators operate at 16 KHz sampling rate and will in addition offer continuous time and amplitude scaling of the envelope functions. The 4A, 4B and 4C systems can be used as real time sound generators, or, for example, as peripheral processors for general music programs where the samples produced might be sent back into the general purpose computer for further processing.

Psychoacoustic studies to aid synthesis.

Digital synthesis requires great amounts of explicit information about the physical nature of the desired sound. Composers possess great amounts of implicit information about sounds both real and imagined, but their knowledge is usually not in a form directly applicable to synthesis. One of the major efforts of research at IRCAM in the past year has been to develop tools allowing composers to make more direct use of their musical knowledge in the synthesis of sound.

The most important such tool developed in the past year has been a group of computer programs called ESQUISSES conceived by David Wessel and written by Bennett Smith. A schematic drawing depicting the general structure of ESQUISSES is shown below (see Appendix 1).

Let us suppose that a composer has collected a fair amount of material for a piece he is working on and would like to learn more about possible relationships between the various elements of the material. He prepares each element as a sound file on the computer (either by digital recording or by direct synthesis). The composer decides in regard to which aspects he wishes to examine the material and calls a program which presents him with all possible pairs of elements and asks him to judge the difference between the members of each pair with regard to each aspect. In general, these "aspects" will be complicated ideas for which the composer does not know the physical correlates, such as aggressivity, opaqueness, weight, predominance of pitch in non-pitched sounds. After asking for these judgements the program prepares a list of the dissimilarities between each element and all the others for each aspect investigated.

These lists are sent to two standard programs of analysis, KYST and HICLUST. KYST searches for the best two dimensional representation of such a list of dissimilarities. That is, it searches for the best way to show the perceived differences (e.g. a and b are very dissimilar, b and c moderately dissimilar, c and a very similar) as geometric distances, thereby constructing a map of the perceptual space in which those sounds reside for that particular aspect.

HICLUST on the other hand attempts to analyse the degree to which perceptual features are shared by the elements. (Referring to the example in the last paragraph, one would conclude that a and c share several features, b and c considerably fewer and that a and b have virtually nothing in common).

The user has immediate access to graphic representations of both these analyses on the screen of his terminal. The single elements are projected onto the keys of the terminal, allowing the user to play the elements at will and thus to explore in detail the perceptual representations arising from the analyses.

Finally, if the user has investigated his material in regard to more than one aspect, he can receive an overall evaluation of the complex perceptual space by sending the dissimilarity matrices to the program INDSCAL, which determines the number of relevant dimensions necessary for a good representation of the data. ESQUISSES then presents two-dimensional representations of each of these relevant dimensions plotted against every other. In contrast to KYST, INDSCAL indicates a unique orientation of the axes of the representation, as well as indicating the relative importance of each dimension.

ESQUISSES can be used by both psychoacousticians and composers. For the scientist the program clearly offers a convenient and quick way to collect data, while giving subjects the chance to interact with the material presented them. However, the real interest of this type of program is in interpreting the analyses, in discovering the actual nature of the order latent in the graphic representations. The scientist will try to find as objective an explanation as possible, most often bringing the perceptual order into relation with the physical structure of the sounds. So, for example, when this program is used to test the perception of timbre, the two-dimensional representation of the results has most often been interpreted by introducing a vertical axis corresponding to the location of the maximal spectral energy (whether in the lower or the higher frequences) and a horizontal axis corresponding to the synchronicity or non-synchronicity of the attacks of the various partials of a sound.

Here the composer seems much freer, for his interpretation of the order inherent in his perception is not obliged to be "objective"; he can choose that interpretation of the representations which renders the most coherent musical vision of the material. If the composer wishes either to adjust elements of the material or to construct elements tracing new paths between known points in the perceptual space, ESQUISSES can help him do so by allowing him to check newly synthesized elements against known ones until the desired results are obtained.

We have dwelt so long on this one project because ESQUISSES seems an important paradigm for future work at IRCAM. The program can be of service to both musicians and scientists. The project was conceived by a scientist who is also a musician, and the final form of the project is the result of a long evolution from an original idea for an automated testing program, an evolution due in large measure to the influence of IRCAM's musicians and their demands. We hope that this model will prove fruitful for other projects as well.

In addition to this large research project, IRCAM sponsored a Symposium of Musical Psychoacoustics from 11 to 13 July 1977, as a satellite meeting to the Ninth International Congress on Acoustics held at Madrid earlier in July. More than 200 people participated in the Symposium, at which 55 presentations were made. IRCAM noted with interest both the number of workers engaged in research on specifically musical psychoacoustics and the general quality of their work.

Instrumental and vocal studies.

Another important aspect of IRCAM's work concerns research in the instrumental and vocal domains. Much of this work has had to wait for the completion of the IRCAM studios in August 1977. Nonetheless, two projects have begun during 1977 which will be continued for at least another year.

The first of these is a study of the multiphonic sounds of wind instruments. Multiphonic sounds are those complex and rather "dirty" sounds to which departures from standard fingerings and embouchures can easily give rise. Composers have for some time been interested in exploiting these sounds, because they represent an alternative to the usual vocabulary, particularly of the woodwinds. There is a great variety of multiphonics ranging from little more than colorations of notes of the chromatic scale to extremely dense and complex sounds. At the same time there is no clear systematic explanation of their production, which means that although a composer may clearly hear in his imagination the sound he wants, he can neither notate it, describe to a wind player how to produce it (unless he can play the instrument in question), nor can he in fact be sure that this particular instrument can give him the sound he requires.

IRCAM has recorded a catalogue of multiphonic sounds, played by both wood and brass instruments. Using some of the psychoacoustic tools available in the ESQUISSES program described above, subjects were asked to order this material according to criteria such as density and perceptibility of one or more clear pitches. The task is now to compare what is known about the acoustics of multiphonic sounds and their production with the structures which arise out of the ordering by ear in the hope that the perceptual structures will offer some aid in developing a scheme for classifying and notating the sounds. This project is being carried out in cooperation with the Laboratoire d'Acoustique of the Université de Paris VI and Professor Emile Leipp.

A second project in the instrumental domain is a study of electrical transducers for musical instruments. Frequently in contemporary music one would like to use what one instrument is playing either as raw material to be transformed in some way, or as a means of controlling some process. Although very good microphones exist for capturing the aerial transmission of sound, they are not well suited to the task mentioned above, because it is virtually impossible to avoid capturing the sound of other instruments as well without being so close to the instrument as to have a markedly distorted sound. The traditional solution to this problem has been the contact microphone, which receives its signal through physical contact with the instrument. However, the quality of commercially available contact microphones is generally poor and often inadequate for serious purposes. The goal of this study is to propose guidelines for the construction of a series of contact microphones of very high quality. Work began shortly *before the end of 1977 and has been devoted largely to the development of* measurement techniques appropriate to the project. Rather exhaustive measurements for the flute have been made as well.

Studies in Room Acoustics.

A further area of research during the past year has been room acoustics. Clearly IRCAM's "Espace de Projection" will be a most important experimental tool for acoustical studies. The first studies will begin early in 1978 and will be carried out by Victor Peutz, the acoustical consultant for the IRCAM building and the acoustical designer of the Espace de Projection. During the past year, Peutz has been preparing measurement programs for use in the Espace de Projection. One of these programs uses a new algorithm developed by Peutz for the determination of reverberation time.

Ideally the reverberation curve within a space represents an exponential decay of sound energy due to absorption within the space. If the space responds uniformly to sound energy introduced into it, that is, if it has but a single mode of response, then the reverberation curve is a simple exponential curve. Physical spaces, however, like physical objects, very rarely exhibit such regular behavior, and a precise description of a given space is likely to be very complex. However, one can compute an accurate approximation of the response based on the mathematical model of several coupled modes of response, each of which contributes more or less independently to the total reverberation time, some having a longer, some having a shorter decay rate.

The reverberation time of a space is normally defined as the time required for an acoustical signal to decrease in amplitude by 60 dB. This measurement is difficult if the ambient noise level is less than 60 dB below the maximum signal level, which is frequently the case outside the laboratory. Furthermore, the mere measurement of reverberation time is less useful than the ability to define mathematically the most important of the contributing components.

The algorithm developed by Peutz calculates the decay and the relative strength of the three components contributing most strongly to the decay curve, one of long duration, one of medium duration, and one of short duration, for each of a number of frequency bands specified by the user. Should there be less than three components, the program so informs the user. This data allows an accurate mathematical reconstruction of the decay curve. From this reconstruction in turn, a great deal of further information can be obtained, such as the time required for the acoustical filling of the space, or reverberation times based on different parts of the curve.

The measurement program, developed at Victor Peutz's laboratories in Nijmegen, Holland, has been installed at IRCAM and will be used for acoustical studies of the Espace de Projection.

Summary of projects for 1978/1979.

The future work of IRCAM will continue along the lines already sketched, becoming however, at once more complex and more general in interest and application in both the musical and scientific communities. The following is a very rapid sketch of projects already begun for 1978 and 1979.

Work will continue on the IRCAM system of sound synthesis for use on general purpose digital computers. In particular, the IRCAM system will be made available to anyone interested, for use on any mini-computer having a minimal amount of core memory and digital-to-analog conversion for the output. In the same fashion, ESQUISSES will also be made available to mini-computer users within the year. With these two systems, a tool immensely rich in potential can be at the disposal of a large number of interested composers.

Work will continue on the construction of the digital synthesizer. In the near future a series of reverberation/filter units will be built, permitting both the reverberation and the filtering of an instrumental or synthesized input in real time. Many of the conceptual problems of constructing a portable digital synthesizer seem to be solved. Two important areas of research remain largely unexplored by IRCAM:

1° The development of rich possibilities of control of the processes of synthesis and transformation of sound (visual, gestural, and tactile input devices), and

2° even more important, the development of a supple and extensible language of control for sound processing which makes use of the vast reservoir of the skill and knowledge which every musician possesses, but frequently can only put to partial use in the confrontation with technology. This project of the development of a language for working with sound is clearly a long-term project. It is also a project on whose realization depends the ultimate success of the considerable technological investment IRCAM has made in sound synthesis.

A long-term project has already began on the investigation of sounds having non-harmonic spectra. This project seems of great interest because of the clear and pervading influence of the structure of sounds themselves on the kinds of hierarchy of relationships which can exist between these sounds. Octaves, fifths and thirds are clearly "privileged" intervals when played by instruments having harmonic spectra, that is, spectra where the frequencies of the partials are integer multiples of the fundamental and where these intervals are contained within the spectra. Played by church bells having non-harmonic spectra, however, octaves, fifths and thirds lose their specialness. For non-pitched instruments like cymbals or drums, even the idea of interval would seem devoid of significance.

For the synthesis and transformation of sound, it would be of great importance to investigate whether hierarchical relations of general validity can be established between sounds having non-harmonic spectra. If in fact such relationships can be established this would mean a significant advance in the control of sound synthesis, permitting the generalizing of scale-like structures to musical objects which hitherto had seemed to resist such ordering.

Another area of research which will remain central to IRCAM is room acoustics. The Espace de Projection offers a unique tool for acoustical studies, and in fact the complex series of tests to determine the basic performance of the Espace will itself be the first research project carried out in the hall. Another research project will make use of the fact that there can be smooth changes of both the amount of absorption in the room and the room's volume to investigate with precision the dependence of reverberation time on absorption, and in particular to validate or invalidate the two (mutually apparently contradictory) classical rules for this dependence that of Sabine and that of Eyring.

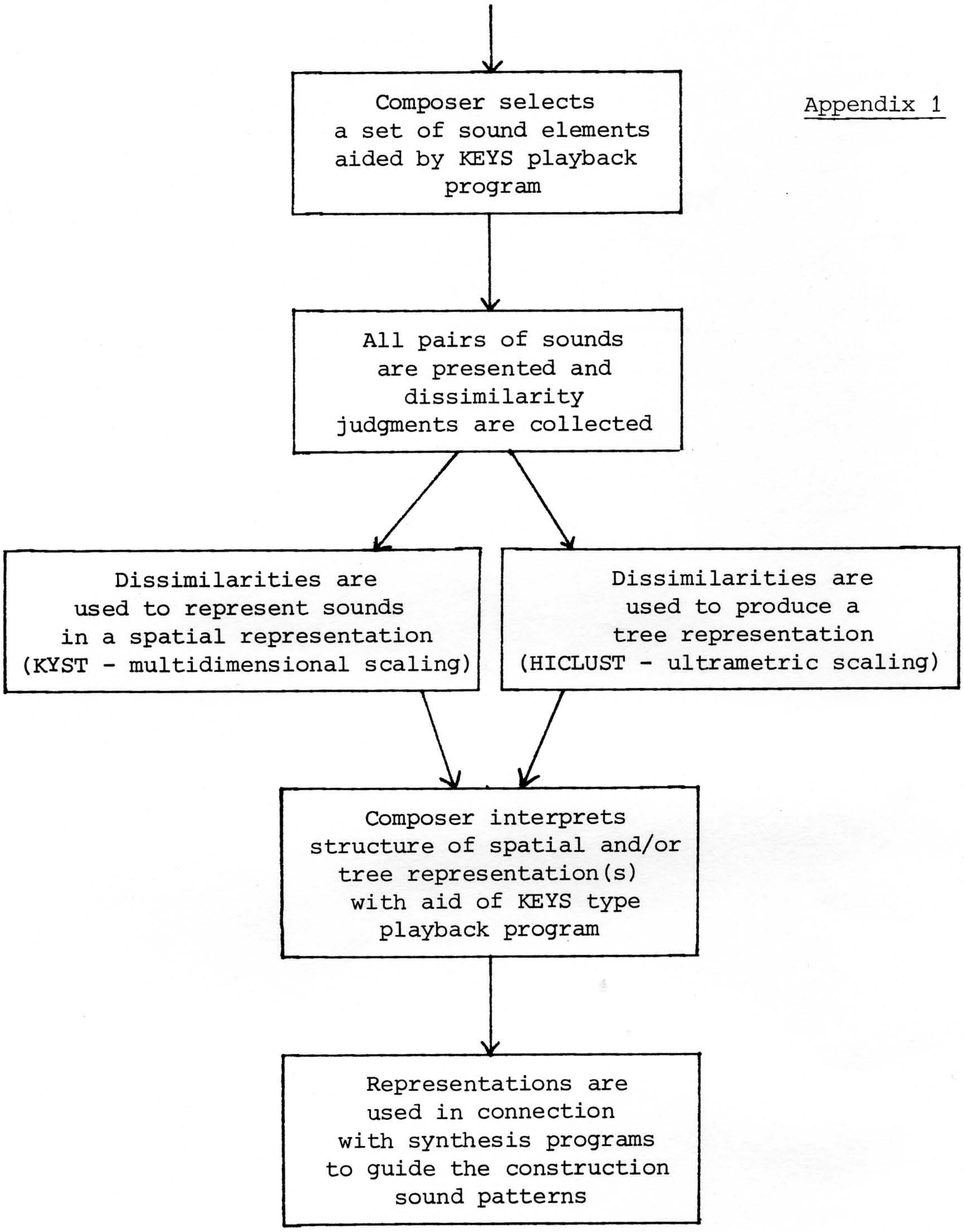
Future research will not be limited strictly to acoustical measurement, but will also move very strongly towards the modelling and simulation of sonorous spaces. This simulation is not only of interest to architects concerned with halls or buildings, but more especially to composers wishing to incorporate the dimension of space into their work as a controllable element.

The Espace de Projection is however not simply a research space. It is also a small concert hall which will provide an immensely rich and enormously flexible field for the experimental presentation of music. Much of the most important research at IRCAM in the years to come will take place in this very room, in the study of new relationships between composer and musician, composer and scientist, composer and audience. A permanent confrontation of music, theater, and science will take place here, and here the artistic reflection which is IRCAM's very reason for being will find its concrete musical expression.

Gerald Bennett
Paris, January 1978

Appendix 1: A block diagram of ESQUISSES.
Appendix 2: List of IRCAM musical and scientific permanent staff in 1977.
Appendix 3: List of musicians, scientists and technicians invited to work at IRCAM during 1977.

Appendix 1



A block diagram of ESQUISSES

Appendix 2.

List of IRCAM musical and scientific permanent staff in 1977.

Directeur : Pierre Boulez

Conseiller Scientifique : Max Mathews

Département Ordinateur

Responsable : Jean-Claude Risset

Ingénieurs/Chercheurs : Jim Lawson
Brian Harvey
John Gardner

Département Electroacoustique

Responsable : Luciano Berio

Ingénieurs/Chercheurs : Giuseppe Di Giugno
David Cockerell
Alain Chauveau

Département Instruments et Voix

Responsable : Vinko Globokar

Ingénieur/Chercheur : René Caussé

Département Diagonal

Responsable : Gerald Bennett

Ingénieurs/Chercheurs : Andy Moorer
David Wessel
Benjamin Bernfeld
Didier Arditi

Département Pédagogique

Responsable : Michel Decoust

Coordination Technique

Responsable : Jean-Pierre Armand

Adjoint au Responsable : Patrick Croix

Appendix 3

The following musicians, scientists and technicians were invited to work at IRCAM during 1977.

Hal ALLES (USA) (from Bell Laboratories) - Research engineer - April 1977 designed and constructed with G. di Giugno the first prototype of the sound synthesis system 4B.

Daniel ARFIB (France) (Université Aix-Marseille) - Researcher. Worked at IRCAM in August-September 1977 to test and debug the new MUSIC V program and to adapt his programs.

Michèle CASTELLENGO (France) (Laboratoire mécanique/acoustique, Université Paris VI) - March-December 1977. Study of the psychoacoustics of multiphonic sounds in wind instruments.

Jacques DE LATTRE (France) (Chef du Service d'exploration fonctionnelle, Hôpital de la Salpétrière, Paris) - Electromyographic study on the physiology of piano playing. (Project supported by the "Direction Générale de la Recherche Scientifique et Technique".)

Martin FROST (USA) (Computer scientist, systems programmer at Artificial Intelligence Laboratories, Stanford University) - Worked on the installation of the computer editing system E.

Andres GERZSÖ (Mexico) (Flutist, Mexico City) - from October 1st 1977, study to develop guidelines for the construction of better contact microphones.

Stanley HAYNES (England) (from City University, London) - Composer and researcher. Worked August 1977 to test computer music programs and used IRCAM's language for computer sound synthesis to realize the piece "Prism".

Lawrence JOHNSON (USA) (from Michigan State University) - Student of Computer Sciences. Worked January-June 1977 to develop and install software for sound synthesis (Music 4B, filter design program).

Jacques MEHLER (France) (Directeur du Centre d'Etude des processus cognitifs et du langage - Ecole Pratique des Hautes Etudes). Study of the ontogenetic bases of musical perception, especially the perception of time in infants. (Project supported by the "Direction Générale de la Recherche Scientifique et Technique".)

Neil ROLNICK (USA) (Composer, doctoral candidate in music at the University of California at Berkeley). Invited composer, working on the development of a language of control for the Di Giugno system 4B.

Christopher SHEELINE (USA) (Graduate Student in Music at Stanford University). Worked July-September 1977 to write the tutorial manual for IRCAM's version of Music V.

Bennett SMITH (USA) (from Michigan State University). Computer programmer. Developed the program necessary for the ESQUISSES system.

Leland SMITH (USA) (Professor of Music, Stanford University). Composer and researcher. Worked April-July 1977 to install SCORE, an extremely powerful language for the coding of music, which produces output directly usable by the Music V program.

Balz TRÜMPY (Switzerland) (Composer, Basel). Worked from January to April 1977 to develop a series of generalized input programs for the Di Giugno system 4A.