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# THE COMPUTER MUSIC FACILITY: A NEW MUSICAL MEDIUM

PROPOSAL

*submitted to:*

The National Endowment for the Arts in conjunction with the proposal "COMPUTER SIMULATION OF MUSIC INSTRUMENT TONES IN REVERBERANT SPACES" submitted to The National Science Foundation

*for:*

Joint support for computer research and composition

*from:*

**The Center for Computer Research in Music and Acoustics**
Department of Music
Stanford University

John M. Chowning, Leland C. Smith - *Co-principle Investigators*
Professor Albert Cohen - *Program Coordinator*
June 18, 1974

## INTRODUCTION

A major American contribution to present and future music exists in the application of a rapidly developing computer technology to the art and science of music. The extraordinary results already obtained have occurred in those few instances where scientists and musicians have taken the opportunity to bring their respective skills to bear on problems of common interest in a rich interdisciplinary environment. It is an example of cooperation, but more, an expression of the freedom of intellect and invention, where creative minds from diverse disciplines have joined in a common goal to produce fundamental knowledge which must be the source for new music, and to produce works of art which reflect the scientific-technological riches of the present. With the approach of the Bicentennial and its commemoration of the past, it seems appropriate that the nation's resources should also be used to give vitality, permanence, and visibility to this uniquely American interaction between science and art.

## PROPOSAL

In order to develop efficient techniques and programs for the simulation and generation of complex auditory signals through the uncovering of fundamental knowledge in psychoacoustics and in order to apply these techniques and knowledge to the composition and performance of music, we are submitting this proposal for joint support to the National Science Foundation and to the National Endowment for the Arts.

We are requesting support from NSF over 24 months for research which is described in the separate proposal, and from NEA, support for permanent equipment as a one-time cost which constitutes a *new medium of musical expression* and which will provide long term service for composition, performance, and related research.

| | | |
|---|---|---|
| Requested from NEA | $245,735 | one-time cost |
| Requested from NSF | $367,038 | for 24 months |

A detailed description of the proposed facility is provided as Appendix A. The Budget is Appendix B. Appendix C lists background information on members of The Center for Computer Research in Music and Acoustics.

## THE COMPUTER MUSIC FACILITY: A NEW MUSICAL MEDIUM

The audio loudspeaker has had a striking impact on human communication: it allows spoken conversation to span distances of thousands of miles, in an instant it makes available to all of mankind the events at any location on earth, and through recordings and broadcasts it allows music to reach an audience far greater than that which can be accomodated by a concert hall. The loudspeaker is a relatively simple technological achievement and its enormous usefulness to humanity results from the fact that it is not only inexpensive but it is a *general* sound source which is capable of reproducing, with more than passable fidelity, the sound of human speech as well as a symphony orchestra.

In the context of musical experience in the 20th century the loudspeaker has become for the audience the principal means of musical communication - far more recordings are sold than are concert tickets - and for composers, the loudspeaker suggests a *direct medium*, comparable to the relationship between creative thought and the media of painters and sculptors.

The search for such a direct medium led to the development of electronic music and its most widely used instrument for controling the loudspeaker, the analog synthesizer. The deficiency of analog synthesis, however, is that it is not sufficiently general to allow the composer to control his material from the elemental level of the sound itself to the higher levels of form. Thus, it has been unable to hold the interest of our best composers, let alone their audience.

Over the past decade, a new medium has evolved which clearly overcomes the problems of analog synthesis and, additionally, offers musical possibilities never before imagined: the computer music system. The computer is a perfect complement to the loudspeaker since it is even more *general* in its capability and it is sufficiently precise to allow the generation of any sound, ranging from those of the natural world to those not yet imagined. The one deficiency has been that the enormous amount of computation required for the generation of complex sounds has prevented the real-time control of those sounds by the performer-composer. In the current system, this means that the interval of time between a musicians final musical decision for a complex multi-voiced passage and the actual production of the sound can be a number of hours. Now the means are available to eliminate this problem.

The special, dedicated system which we propose maintains the generality of the large computer system while utilizing the new technology to advance computer music systems to the level of practical real-time performance and composition. The proposed equipment constitutes a small but powerful computer facility for the purpose of real-time digital synthesis and signal processing. In addition, the system is designed to accommodate a time-sharing system, which will support a number of composers-researchers in simultaneous computing activities. The facility will exist as a satellite system to the large computer at the Stanford Artificial Intelligence Laboratory, an environment which has proven to be a rich resource in its high level of technical competence and its interdisciplinary population of users.

*The facility as a Musical Instrument:*

The facility must be seen as the most flexible of musical instruments. To speak of the facility as a conventional musical instrument, however, is somewhat misleading because the system is capable of simultaneously producing a large number of independent voices having arbitrary timbral characteristics; it is much more general than a conventional musical instrument. As with any other instrument, it must be studied in order to be useful, but once learned, it is an instrument of enormous potential; it can generate any sound that can be produced by loudspeakers, modify and transform real sounds entered into the system by means of microphone, remember and modify articulated musical input, and simulate the location and movement of sounds in a variety of illusory reverberant spaces. Equally important, the facility will be capable of serving a number of composers, providing for each a direct control over his medium which was never before possible. The facility can be a performing instrument where the musician directly controls the sound through a keyboard, knobs, or any other man-machine interface.

*As a Research tool:*

Research over the past 15 years, begun at Bell Telephone Laboratories and extended to a few universities, has shown the computer to be an extremely powerful device for musical and acoustical research. Based on this past experience, the proposed facility will maintain those attributes of generality, flexibility, and precision which have been of utmost importance in the research performed to date. In addition, its real-time, interactive capability will allow a kind of research in the perception of complex signals that is not currently possible.

*Bibliographic and Archival applications:*

Research already begun at the Center has important implications for music libraries and sound archives. The manuscript program developed here would allow composers to generate their scores directly by means of the computer, in a form that is easily edited and which can be reproduced at engraver quality at a fraction of the cost. Techniques and equipment will be available to preserve recordings in a 'digital' recording archive, which form of storage suffers no degradation through time. Every dubbed copy is equal in quality to the original. Multiple copies could be made and stored in different parts of the country, each with essentially *perfect* fidelity.

*As a Prototype for Other and Future Systems:*

The facility which we propose will be composed of equipment that is now in production and generally available. The single exception is the digital signal processor which will be the prototype. The next few years will bring yet newer advances in the miniaturization and increased speed of circuitry. To the extent that we are prepared through sufficient knowledge and adequate techniques, small computer systems will be as commonplace as 'synthesizers' are in the present.

The research and development of programs and techniques which will be done at the center, will serve as a prototype and a point of departure for systems which are developed elsewhere. In addition, the teaching of composers and dissemination of information will contribute to the useful application and utilization of the new technology.

## PROGRAMS OF THE CENTER

The facility must be considered as a national resource. In addition to the service of the proposed facility to teaching, research, and creative activities within the university, the programs below are designed to make the facility available to those researchers and composers in the national community whose interests would be accomodated by the facility.

*Summer workshops*

As an addition to the normal teaching and research function during the academic year, the Center will hold special summer workshops for musicians and scientists from outside the university. Three such workshops have been held since 1969, with students attending from this country and abroad. In a six-week session, the students are able to learn basic computer programming, fundamentals of acoustics and psychoacoustics, and produce a composition. Given the proposed facility, this program could be significantly expanded.

*Composers in Residence*

A program will be developed where major composers are invited to work as guests of the Center for an extended period of time. This would not only aid in the dissemination and utilization of research results, but would contribute to the general level of artistic activity in the San Francisco area. Györgi Ligeti has already expressed interest in such a program at Stanford. For American composers, the program could be coordinated with the support of the NEA. The composer stands to benefit greatly from the existence of such a facility. The freedom of expression available from a powerful computer is very great indeed.

*Publications and Performances*

A normal function of the Center, indeed an obligation, will be the publication of results on a lay level as well as technical. Publications and tapes for performance could then be made available to large numbers of communities throughout the nation through the Executive Directors of the State Arts Councils.

*Site Visits and Symposia*

It is a normal circumstance to have a large number of visitors at the Stanford Artificial Intelligence Laboratory. Over the past years we have given demonstrations to groups ranging from school children to professionals in the field. With a relatively independent satellite system as proposed, we could significantly expand visits without causing inconvenience to the main laboratory.

San Francisco is a major national conference center for associations in both the sciences and humanities. Special symposia could be coordinated with conferences which have interest in technological applications, music, or both.

# BICENTENNIAL PROGRAM

## Research in Psychoacoustics, Computers, and Music as a Bicentennial Activity

Of all the human activities which lie at the intersection of art and science, there is none that has been so productive and compelling, nor so filled with promise for the future as that activity which surrounds music and computers. Totally dependent upon advanced computer technology, it is an activity which, through its potential for solutions and the intensity of artistic need, has given definition to musical-acoustical problems which until now have been beyond the general research capability. The work already accomplished has produced new and novel tools for both the exploration of complex auditory processing and the composition and performance of music, which in turn has induced a substantive participation by researchers from a number of disciplines: music, computer science, psychology, physics, mathematics, and engineering. It is an example of cooperation, but more, an expression of the freedom of intellect and invention, where creative minds from these diverse disciplines have joined in a common goal to produce fundamental scientific knowledge which must be the source for new music.

This intersection of music and computers developed in the United States, and found its base in the rich inventive-scientific-technological activity which is one of the most distinctive aspects of our country's heritage. With the approach of the Bicentennial and its commemoration of the past, it is appropriate that the nation's resources should also be used to give vitality, permanence, and visibility to this uniquely American interdependence of art and science.

1974? – Stanford University's Center for Computer Research in Music and Acoustics has the opportunity to bring to a large public a new music which is dependent upon scientific research and technology to a degree that never before existed.

As a part of the nation's Bicentennial, we propose that the Center at Stanford, an example of computer based interdisciplinary research and composition, organize a series of concerts of computer music, lecture-demonstrations, laboratory visits, and a symposium in the Spring and Summer of 1976. In this way, the public can share the excitement of applying its advanced technology to the discovery of new knowledge regarding sound and perception and to new means for the composition and performance of music.

## BACKGROUND

Stanford University was the first to develop a self-contained, interactive system for direct digital synthesis. Over a period of nine years we have developed programs and techniques for the composition of music, the editing and publication of high-quality manuscripts, the simulation of moving sound sources using four speaker-channels, the simulation of a variety reverberant environments, and the analysis and synthesis of complex auditory signals, some of which are both simple in implementation and novel in conception.

We have provided in recent years a growing number of universities with our programs and special knowledge, including Columbia, Princeton, Michigan, Caltech, and Dartmouth. At two universities, Colgate and Carnegie-Mellon, we provided our entire set of synthesis and composition programs. It should be pointed out that this is a natural extension of an original service extended to Stanford by Bell Telephone Laboratories when we were first beginning our work.

# APPENDIX A: EXISTING AND PROPOSED FACILITIES

## A. EXISTING FACILITY

### 1. HARDWARE

All of our research to date has been done at the Stanford Artificial Intelligence Laboratory, a highly developed computer system representing an investment of roughly two million dollars.

The facility is organized as an interactive time-sharing display-oriented system. Powerful graphical and interactive techniques are available as well as a host of computer languages, library functions, utility routines, and text manipulation programs. The system is well human-engineered so as to make research convenient and natural.

The laboratory itself serves Stanford professors, research associates, and graduate students, principally in the field of artificial intelligence research, but with other concerns, such as the mathematical theory of computation, speech research, and computer aids to autistic children. It is a delightful place to work due to the very diverse interests and skills of the participants, as well as the computational power of the facility.

In addition to the facilities owned by the laboratory, the Stanford Department of Music has provided most of the following audio equipment:

*14-bit 50Kc Analog to Digital converter*
*with 4 channel multiplexing,*
*16-bit 200Kc Digital to Analog converter*
*with 4 channel multiplexing,*
*Scully 4-track tape recorder,*
*4 Dolby System A noise reducers,*
*Sony 4-track tape recorder,*
*2 Dynaco 70 watt stereo amplifier,*
*4 Altec 804 monitor speakers.*

## 2. EXISTING RESEARCH SUPPORT SOFTWARE

In the course of our work, we have developed a number of original and useful programs. It is beyond the scope of this proposal to give a complete description, or even a complete list of all the programs we have written. Some of the principal ones are briefly listed below:

### *GENERAL-PURPOSE PROGRAMS*

The heart of our experimental sound generation is a highly flexible acoustical compiler which is an ALGOL-based descendant of Bell Laboratory's MUSIC V system. This program enables us to produce sounds by any known synthesis technique as well as experiment with new techniques. We have been able to program versatile reverberation routines, spacial localizing routines, and many others.

To connect the synthesis programs with the audio system, there is a set of programs which communicate with that system. For playing synthetic tones, there are programs which can send a disk file to the digital-analog converter for any combination of available sampling rates and channel selections. Monaural, stereo, and quadraphonic files can be played and recorded on any of the tape recorders. Natural sounds can be digitized and stored on disk files. There are sound file editors which can display a segment of a digitized waveform, synthetic or natural, which can display the discrete Fourier transform of a segment of sound, select sub-segments from longer sound files, and many other splicing and editing functions.

A program is available which allows a composer to communicate his ideas with the music synthesis program in a natural and convenient manner. All he need do is list what notes are played and what instruments are playing, and the program produces automaticaly the proper input for the synthesis program. This same input with only minor modifications can be used to produce a high-quality printed score. Provisions are in for allowing such musical nuances as glissandi and crescendo, control over time such as rallentando and accelerando, and many others. The program can also exercise some choice for the composer by the use of random numbers. The composer can have the machine select different options at random, such as pitch or duration of a note.

A general purpose function generating program allows the user to specify the sinusoidal components of a complex wave, with control over amplitude and phase of each component. In addition, the program is used to generate time-domain functions by means of numerical specification or by use of a light-pen. The program stores all functions as a file on the disk memory.

*PROGRAMS FOR REVERBERATION AND LOCALIZATION RESEARCH*

We have written an interactive reverberator compiler which aids the user in the design of reverberators (Section IIB1 of the NSF proposal) which can be used to reverberate any stored sound file or any synthesized sound. The program calculates reverberation parameters, generates and displays the resultant program language description of the reverberator as it is being constructed, and displays and plays (on command) the impulse response of the reverberator as each unit of the reverberator is defined.

An interactive graphic program has been developed for the control of a moving sound source trajectory in the simulated two-dimensional space (Section IIB2 of the NSF proposal). The program accepts input from the teletype to specify a computed trajectory, or from the light-pen to specify a 'hand' determined trajectory. The program derives the control functions for azimuth, distance, and velocity, displays them, and stores them on the disk, on command.

*PROGRAMS FOR THE EDITING AND PUBLISHING OF MUSIC MANUSCRIPTS*

A versatile and easily used program for the creation and printing of music manuscripts has been in use here for almost a year. This program allows not only classical notation, but graphical notation as well. The composer can draw his own symbols and use them in any size or position. Music manuscripting has traditionally been a difficult job requiring great artistic skill. The program allows easy modification of the score, and can automatically extract parts and transpose keys. A wide range standard musical symbols have been entered and are available for use. The composer can 'grab' a phrase and move it about, delete it, replicate then edit it, transpose it, invert it, and otherwise deal with it as a unity, as well as deal with its component parts. Spacing of notes along the staff can be done automatically.

*PROGRAMS FOR MUSIC INSTRUMENT RESEARCH*

A set of programs exist which implement the heterodyne analysis of music instrument tones (Appendix A of the NSF proposal). The first pass includes FFT's for overlapping windows, which are processed in the next pass to determine average frequencies of the harmonics of the tone. In the next pass, these frequencies set the heterodyne filter both in window size, the fundamental period, and center frequency, the particular harmonic being analyzed. The output is a set of time-varying frequency and amplitude functions for each harmonic listed. The final pass consists of a heuristic program which extracts, by an examination of phase variation and amplitude, the analyzed sound segment which most probably corresponds to the actual tone. It scans the functions for new estimates of the average frequencies of the harmonics, their peak amplitudes, and extracts various other information on the tone. At this point, or above, data compression by any power of two can be performed by an averaging technique.

Another set of programs are used to display, plot, and modify the analyzed functions obtained above. Three-dimensional rotation of perspective plots of the amplitude or frequency functions for the whole set of harmonics, temporal line-spectrum displays, spectrographic displays, and many other forms of graphics are obtainable. Furthermore, a host of operations can be performed on the analyzed functions, including smoothing, light-pen modification, line-segment approximation, spectral envelope modification, amplitude and frequency modulation, and many more which serve as tools for research.

Another program is used for optimized additive synthesis, based on the directly analyzed or modified functions (Section IIA1 of the NSF proposal). Tones can be synthesized at arbitrary frequencies, amplitudes and durations, from any specified list of amplitude and frequency functions, paired as desired. This allows for the generation of a tone with a reduced set of harmonics, or a set of harmonics from different instrumental origins, or the pairing of arbitrary amplitude and frequency functions from different instruments or having differing operations performed beforehand. Furthermore, procedures can be written for this synthesis program which allow for further data manipulation, as in the interpolation between two tones. The program is capable of reverberation, and accepts any arbitrary note/procedure list which specifies a temporal ordering of events, each having associated parameters for synthesis operations.

A dynamic display program is used for evaluating the results of decisions in frequency modulation (FM) synthesis (Section IIA2 of the NSF proposal). The amplitude of the frequency components are displayed as a function of time where the modulation index is interpolated between any two values. The program asks for a ratio of carrier to modulating frequencies, beginning and ending values of the index, and the number of steps in the interpolation. The displayed information includes the value of the index at every step, so that the user can interrupt the interpolation to examine the spectral shape in relation to the value of the index.

An equally useful representation of the same data exists in a three-dimensional interactive display program. In this program, the effect of complex functions for both amplitude and modulation index can be examined as they affect the spectrum shape.

*PROGRAMS FOR PERCEPTUAL EXPERIMENTATION*

A whole host of programs exist which conduct on-line psychoacoustical experiments, playing tones over the D-A converter, allowing listeners to hear stimuli again, often in any order. (It should be mentioned that the proposed real-time system would make it possible for listeners to manipulate various parameters of stored signals and get immediate feedback. This would give us a much greater tool to uncover the most important aspects of the perception of instrument tones.) Responses of listeners are taken, stored, and eventually analyzed by other programs, e.g. analysis of variance and multidimensional scaling.

A particularly useful program exists for the display of multidimensional scaling experiments. Using a series of mirrors, it allows the viewer to see convincing three-dimensional configurations in realistic perspective. Rotation can be performed, and two configurations can be observed and compared simultaneously.

## B. PROPOSED FACILITY

### 1. HARDWARE

Even though our current facility represents the most sophisticated computer music system in existence, the processes used to produce music by computer require great quantities of both computer time and human time, with some rather severe limits of flexibility. Since it is the musician's 'ear' which must be the final judge of musical results, many experiments must be done before a desired musical quality can be reached, and the computations can take as much as 100 times the length of the music produced. This requires great patience from the user, and for large sound-segments can put to the test our relationship as guests on an already busy computer system.

For this reason, and to further aid in the development of this important medium, we propose a special-purpose computing system. The system would initially be a satellite of the Artificial Intelligence Laboratory computer system, but would serve not only to reduce the computation load of the current facilities, but by means of special-purpose hardware would actually produce musical tones that can be dynamically moved to arbitrary positions within a simulated reverberant space of arbitrary size, and do this in real time.

The system would be powerful enough to stand alone if necessary, but it would be extremely expensive to purchase a system with the human engineering of the AI lab facility. We therefore propose to use the AI lab facility as an interface to the special-purpose system, thus minimizing change-over inconveniences and initial setup price. As work continues, it would be possible to upgrade the system to stand alone and eventually provide a high degree of service without the aid of the AI facility. To this end, we propose using an existing time-sharing system as the resident monitor in the special-purpose system. This saves us the trouble of having to write device controllers, memory management programs, and other system-level functions. Since we propose to begin with a time-sharing system, upward compatibility is assured. Programs will continue to run unmodified as the system is upgraded. This use of off-the-shelf equipment will make it possible to replicate the system anywhere. The software we develop will be available for use at any new installation.

A detailed budget is given in Addendix B and a more detailed description of the proposed facility is given in Section VB of the NSF proposal. The following is a list of the principal components of the proposed facility:

*Digital Equipment Corporation PDP-11/45 Computer*
*with floating-point unit*
*and memory management module.*

*Bell Laboratories UNIX time-sharing system and*
*software support package.*

*Digital Equipment Corporation RP03 disc drive.*
*Provides 20 million 16-bit words of storage.*

*Systems Concepts signal processor with digital*
*reverberation module.*

*Digital Equipment Corporation GT-40 graphics terminal.*

*Audio equipment, including 8-track tape recorder, 8-channel amplifiers and matched speakers, microphones, interface and mixing equipment, acoustical recording module, and acoustically treated listening room.*

The Systems Concepts Signal Processor is the most important item of the proposed facility. It is a highly-parallel, special-purpose, programmable, digital processor designed especially for the generation and processing of audio signals. Together with the 48K reconfigurable bulk storage for programmable reverberation, it provides enough power and flexibility to synthesize in real time all the variety of musical timbres (or even entire compositions) that we have produced to date, and this even with the added enhancement of spacial localization and 4-channel reverberation. It can also do the computations in the heterodyne filter analysis in real time.

When one attempts to generate sounds using a new technique, often there is no good way to make an *a priori* prediction on the range of the controlling parameters. A good example of this is deciding over what range to sweep the modulation index of an FM instrument. With our current turnaround time, one must 'shoot in the dark' in attempting to find the correct parameter, often wasting tremendous amounts of computer time as well as personal time in the process. The PDP-11/45 by itself offers no speedup, but combined with the Systems Concepts Signal Processor, provides the solution to the problem. It would be possible to directly connect a knob, via some PDP-11 support software, to synthesis parameters, thus allowing the experimenter to directly control the parameter as the sound is generated. This increases the efficiency of the research process immensely.

The sensitive musical ear is capable of penetrating to an amazing degree the qualitative aspects of a complex musical event, and we do this in real time. It is often more satisfactory to make changes in a sound as we are listening to it than to try to anticipate the changes desired in a remembered sound. Much as a conductor shapes an orchestral performance in real time, the composer would be able to shape his music as it is played by the computer. An obvious example is the control of the flow of time, or tempo, of a work. Another possibility, and one which the orchestral conductor would certainly wish for, would be the ability to control various aspects of the tuning of the piece as it progresses.

We plan to add to the signal processor the reverberation memory option. This device provides for a number of variable-length digital delays which are easily interfaced with the signal processor itself to provide reverberation in all the forms we have realized to date, and have enough generality to provide for any future forms of reverberation we may discover. Again, the parameters of the reverberation could be easily attached to knobs, giving the user direct real-time control over the character of the reverberation. Thus, the reverberation characteristics of a composition, or its perceived 'room quality,' could become a compositional parameter of the work.

The GT-40 display console is a general-purpose graphics terminal. It provides a direct graphical interface to the PDP-11 and thus to the Signal processor. As is noted often in the NSF proposal, the use of computer graphics is an essential piece of human engineering that we take advantage of constantly. The AI facility has made graphics highly available and easily used. It thus has crept into many programs as a debugging aid as well as a research aid. It is, of course, essential for good music manuscripting.

The audio equipment is the final stage of the sound production. The waveform must be converted to sound by an audio system whose quality matches the extreme quality of digital synthesis. We propose to place eight speakers in an acoustically treated room for listening tests. The number 8 is somewhat of a compromise with cost, as we have little *a priori* reason to believe that eight channels will be enough. However, our current success with four channels and the practical anticipation that eight will be the next widely accepted loudspeaker mode after four, lends some justification to exploring this mode as the next limit.

Of equal importance to high quality audio equipment is a well designed listening room. Computers require extensive cooling and air conditioning, making the computer room sound somewhat like a continuous hurricane. In addition, the particular building we are in uses forced-air cooling in each room, adding a gentle but disturbing hiss to all offices. To do perceptual testing, which is necessary in order to insure perceptually relevant musical decisions, it is essential that the acoustical environment be controlled entirely by the investigator.

## 2. PROPOSED RESEARCH SUPPORT SOFTWARE

An amount of software would have to be written to integrate the proposed system into the current system. This could be done in layers, each preserving compatibility with the previous systems but each advancing the researcher's capabilities. The following discussion attempts to summarize the software which would have to be developed.

### *THE PDP-11 MONITOR*

Although we intend to use the UNIX time-sharing system from Bell Laboratories as a base, it will need some amount of modification to deal with our specific set of peripherals: the GT-40, the RP03 disk, the PDP-10 interface, and the Signal Processor. It is not expected that this would require a great deal of effort to get a basic monitor up and running. Improvements and streamlining can always be added later as the need arises.

### *THE SIGNAL PROCESSOR*

Writing software for the Signal Processor presents somewhat of a problem. One must provide methods not only for setting up the internal computation flow, but also for synchronization and data transfer with cooperating PDP-11 processes. One example might be interactive control of mixing natural and synthesized sounds. The PDP-11 would be reading analog to digital converter output, interactive knob settings, as well as controlling the signal processor and providing it with the parameters read from the knob and the waveform from the A/D converter all at once. The theory of cooperating parallel processes, however, is rather well developed such that straightforward methods can be applied here with little difficulty. It is a great advantage that the UNIX time-sharing system provides for parallel processes and has a highly developed inter-process communication system. Only slight modifications would have to be made to provide for real-time interaction. The efficiency of the inter-process communication system would have to be examined and possibly reprogrammed to assure that it does not incur prohibitive overhead.

The ability to store the output of the signal processor is quite important. The most compelling reason is one of growth. As we progress, it is quite possible that we will demand computations so complex that even the Signal Processor can not complete them in real time. In this case, we must have the option of directing the output to the disk. In this manner, we could break up the computations into smaller runs and mix them in the PDP-11 for later playback.

There are also many utility routines that would have to be written for the PDP-11. We would need an implementation of the fast Fourier transform algorithm, an intermediate-level graphics package for convenience in displaying complex functions, routines for getting at the digital-analog converters, as well as ways to direct asynchronous processes in a uniform and convenient manner.

All of this is programming support that would be needed for interfacing our current research to the new system. Eventually, we would begin writing research programs directly on the PDP-11.

# APPENDIX B: BUDGET

RESEARCH GRANT PROPOSAL BUDGET
TWO YEARS BEGINING 1 APRIL 1975

| Budget Category | YEAR 1 Requested From NEA | YEAR 1 Total Costs | YEAR 2 Requested From NEA | YEAR 2 Total Costs |
|---|---|---|---|---|
| A. SALARIES & WAGES*: | | | | |
| 1. Senior Personnel | | | | |
| a. Smith, Leland C., Professor, Co-principal Investigator, 25% 6 months FTE | $ 0 | $ 5,346 | $ 0 | $ 5,774 |
| b. Chowning, John M., Research Associate, Co-principal Investigator, 100% 24 months FTE | $ 0 | $19,200 | $ 0 | $20,736 |
| c. Cohen, Albert Chairman, Music Department Program Coordinator, 10% 2.4 months FTE | $ 0 | $ 2,900 | $ 0 | $ 3,132 |
| 2. Professional Personnel | | | | |
| a. Rush, Loren, Research Associate, 100% 24 months FTE | $ 0 | $17,280 | $ 0 | $18,663 |
| b. Grey, John M., Research Associate, 100% 24 months FTE | $ 0 | $14,256 | $ 0 | $15,397 |
| c. Moorer, James A., Research Associate, 100% 24 months FTE | $ 0 | $14,256 | $ 0 | $15,397 |
| d. -------------, Systems Programmer, 100% 24 months FTE | $ 0 | $12,960 | $ 0 | $13,997 |
| 3. Student Research Assistants | | | | |
| a. -------------, Student Research Ass't., 50% Acad. Yr., 100% Summer 15 months FTE | $ 0 | $ 5,070 | $ 0 | $ 5,070 |

* Salary increases are projected at 8% per year

| | | | | |
|---|---|---|---|---|
| b. -------------, Student Research Ass't., 50% Acad. Yr., 100% Summer 15 months FTE | $ 0 | $ 5,070 | $ 0 | $ 5,070 |
| 4. Other Personnel | | | | |
| a. Baur, Q., Secretary, 20% 4.8 months FTE | $ 0 | $ 1,981 | $ 0 | $ 2,140 |
| Total Salaries and Wages | $ 0 | $98,313 | $ 0 | $95,236 |
| B. STAFF BENEFITS: | | | | |
| 4-1-75 to 8-31-75 @ 18.0% | $ 0 | $ 7,374 | | |
| 9-1-75 to 8-31-76 @ 19.0% | $ 0 | $10,897 | $ 0 | $ 7,540 |
| 9-1-76 to 3-31-77 @ 20.0% | | | $ 0 | $11,111 |
| | $ 0 | $18,271 | $ 0 | $18,651 |
| C. TOTAL SALARIES, WAGES AND STAFF BENEFITS: | $ 0 | $116,584 | $ 0 | $113,887 |
| D. PERMANENT EQUIPMENT: NOTE: Contributions from Non-government sources are being sought for 50% of the permanent equipment costs. | | | | |
| PDP11/45 with Accessories | $ 33,043 | $ 66,085 | $ 0 | $ 0 |
| UNIX Time-Sharing Monitor | $ 10,000 | $ 20,000 | $ 0 | $ 0 |
| Special Purpose Processor | $ 35,000 | $ 70,000 | $ 0 | $ 0 |
| Disk Controller and Drive | $ 15,500 | $ 31,000 | $ 0 | $ 0 |
| Disk Packs | $ 250 | $ 500 | $ 0 | $ 0 |
| Display System and Interface | $ 6,845 | $ 13,750 | $ 0 | $ 0 |
| Simmographics tablet | $ 1,250 | $ 2,500 | $ 0 | $ 0 |
| 8 Channel Tape Recorder | $ 6,000 | $ 12,000 | $ 0 | $ 0 |
| Amplifiers | $ 500 | $ 1,000 | $ 0 | $ 0 |
| Speakers | $ 1,200 | $ 2,400 | $ 0 | $ 0 |
| Dolby Units | $ 1,250 | $ 2,500 | $ 0 | $ 0 |
| Acoustical Module | $ 2,000 | $ 4,000 | $ 0 | $ 0 |
| Acoustical Room | $ 10,000 | $ 20,000 | $ 0 | $ 0 |
| Total Permanent Equipment | $122,868 | $245,735 | $ 0 | $ 0 |
| E. EXPENDABLE EQUIPMENT AND SUPPLIES: | $ 0 | $ 1,000 | $ 0 | $ 1,000 |
| F. TRAVEL: | | | | |
| 1. Domestic | $ 0 | $ 1,700 | $ 0 | $ 1,700 |
| G. PUBLICATION COSTS: | $ 0 | $ 1,000 | $ 0 | $ 1,000 |
| H. EQUIPMENT RENTAL: | | | | |
| IBM Disk Rental | $ 0 | $12,000 | $ 0 | $12,000 |

| | | | | |
|---|---|---|---|---|
| I. CONSULTANT COSTS: | | | | |
| John R. Pierce | $ 0 | $ 2,500 | $ 0 | $ 2,500 |
| J. OTHER COSTS: | | | | |
| Office Supplies, Communications, etc. | $ 0 | $ 1,500 | $ 0 | $ 1,500 |
| K. TOTAL DIRECT COSTS: (A thru J minus D) | $ 0 | $136,284 | $ 0 | $133,587 |
| L. INDIRECT COSTS: 47% Of Total Direct Costs | $ 0 | $ 64,054 | $ 0 | $ 62,786 |
| M. TOTAL COSTS: | $122,868 | $446,073 | $ 0 | $196,373 |

# APPENDIX C: PERSONNEL

## Leland C. Smith

BORN: August 6, 1925 in Oakland, California.

EDUCATION:

Musical studies with Darius Milhaud, Mills College, 1941-43, 1946-47.
A.B. & M.A. (Music) with Highest Honors, University of California, Berkeley, 1946-48.
Musical studies with Olivier Messiaen, Paris Conservatory, 1948-49.

AWARDS AND FELLOWSHIPS:

Various undergraduate and graduate fellowships, 1946-48.
Phi Beta Kappa, 1948.
Mills College commission for centenial celebration.
Fromm Music Foundation comission for Boston Symphony Players.
Copley Foundation Award.
Fulbright Senior Research Grant, to compose in France, 1964-65.

PROFESSIONAL EXPERIENCE:

Assistant to Roger Sessions, University of California, Berkeley, 1950.
Bassoonist: Chicago Symphony, San Francisco Symphony Orchestra, the orchestras of the Chicago and San Francisco Opera Companies and the New York City Ballet, 1950-59.
Instructor, Mills College, 1951-52, summer sessions of 1953, 1956 & 1957.
Assistant Professor of Music, University of Chicago, 1952-58.
Associate Professor of Music, Stanford University, 1958-1968.
Professor of Music, Stanford University: In charge of Doctoral program in musical composition; Taught a variety of music history and theory courses, including computer applications, 1968 to present.

RECENT PUBLICATIONS:

*Score, A Musician's Approach to Computer Music,* J. Audio Eng. Soc., Jan-Feb, 1972.
*Editing and Printing Music by Computer,* Journal of Music Theory, Fall, 1973.
*Henry Cowell's 'Rhythmicana,'* Yearbook for Inter-American Research, 1973.

RECENT PUBLIC LECTURES:

Lectured on computer music at Colgate University, Columbia University, Michigan State, Univ. of Nevada, Univ. of Calif. at Davis, Univ. of Calif. at San Diego, Calif. Institute of the Arts, Paris U.S.I.S, Yugoslav Composers' Union at Belgrad and Zagreb. 1969-74.

MAJOR PERFORMANCES:

*Symphony I,* San Francisco Little Symphony.
*Santa Claus* (opera, libretto of e.e. cummings), Univ. of Chicago.
*Concerto for Orchestra,* Orchestra of America, Richard Korn cond., Carnegie Hall, N.Y.
*Machines of Loving Grace* (for computer, bassoon and narrator), Town Hall, New York City.
*Rhapsody for Flute and Computer,* many performances in Europe and U.S.A.

## John M. Chowning

BORN: August 22, 1934 in Salem, New Jersey.

EDUCATION:

Navy School of Music and Military Service, 1952-55.
Bachelor of Music, Wittenberg University, Springfield, Ohio, 1959.
Studies in composition and theory with Nadia Boulanger, Paris, 1959-62.
M.A. (Music) Stanford University, 1964.
D.M.A. (Doctor of Musical Arts) Stanford University, 1966.

AWARDS AND FELLOWSHIPS:

IBM Graduate Fellowship, 1964.
Stanford Wilson Fellowship, 1965.
National Endowment for the Arts Fellowship Grant, 1973.
Guest Artist, City of Berlin, 1974.

PROFESSIONAL EXPERIENCE:

Co-director, Society for the Performance of Contemporary Music, 1962-66.
Lecturer in Music, Stanford University, 1966.
Asistant Professor of Music, Stanford, 1967-74.
Director, Computer Music and Acoustics Group, Stanford, 1966-74.

RECENT PUBLICATIONS:

*The Simulation of Moving Sound Sources,* J. Audio Eng. Soc. 19,2-6, 1971.
*The Stanford Computer Music Project,* Numus-West 1, 1972.
*The Synthesis of Complex Audio Spectra by Means of Frequency Modulation,* J. Audio Eng. Soc. 21,526-534,1973.

PUBLIC LECTURES AND PERFORMANCES:

*Computer Music,* Radio Broadcast, KCBS, San Francisco, 1965.
*New Directions in Musical Composition: Computer Generated Music,* lecture-demonstration, Stanford, 1965.
*Computer Generated Music,* lecture-demonstration, Interdisciplinary Computer Symposium, Stanford, 1966.
*Composer and Computers: The Significant Possibilities,* lecture-demonstration, American Musicological Society, Stanford, 1966.
*Sabelithe II,* computer composition in 4 channels, performance, Stanford, 1971.
*Turenas,* computer composition in 4 channels, performance, Stanford, 1972.
*Turenas,* lecture-performance, Berlin & Darmstadt, 1972.
*Turenas,* lecture-performance, Stockholm, Paris, Marseilles & Utrecht, 1973.

PATENTS AND INVENTIONS:

*Method for the Simulation of Moving Sound Sources,* patent granted, 1971.
*Method of Synthesizing a Musical Sound by Means of Frequency Modulation,* patent pending.

## John M. Grey

BORN: February 2, 1947 in Glendale, California.

EDUCATION:

Studied piano and music theory with Lowndes Maury, 1964-70.
B.A. (Psychology and Music) Magna cum Laude, with Highest Departmental Honors, University of California, Los Angeles, 1970.
Studied harpsichord with Margaret Fabrizio, 1970-73.
Ph.D. Candidate (Psychology) Stanford University, dissertation: *On the Perception of Music Instrument Tones.*

AWARDS AND FELLOWSHIPS:

Various undergraduate fellowships, University of California, Los Angeles, 1966-70.
California State Scholar, 1966-71.
National Science Foundation Fellowship for Undergraduate Research, 1969.
Woodrow Wilson Fellow, 1970.
Phi Beta Kappa, 1970.
Various graduate fellowships, Stanford University, 1970-74.
Sigma Xi Fellow, 1971.
Sigma Xi Research Grant, 1971.
Social Science Research Training Fellowship, 1974-75.

PROFESSIONAL EXPERIENCE:

Teaching Assistant (Psychology), Stanford University, 1970-74.
Computer Programmer, Music Education, Stanford University, 1972.
Consultant, computer music, Colgate University, 1973.

PUBLICATIONS:

*Consonance of Pure-Tone Triads in Temporal Isolation and in Sequences,* (with W. J. Dowling) Journ. Acoust. Soc. Amer., in revision for publication (1974).

PUBLIC LECTURES AND PERFORMANCES:

*Consonance and Pleasantness of Tones in Temporal Isolation and in Sequences for Musicians and Non-Musicians,* Western Psychological Association, Los Angeles, 1970.
*The Computer Generation and Graphic Representation of Instumental Timbres,* Project for Music Experiment: Conference on Computer Programming in Music, University of California, San Diego, 1973.
*Computer Generated Sound for Music and Research in Acoustics,* Syracuse Univ., 1973.
*Time Boxes,* computer composition in 2 channels, performance, Stanford, 1971.
*New Loops,* computer realization of score by Robert Erickson in 2 channels, performance, Michigan State University, 1974.
*Psychoacoustics and the Computer Synthesis of Musical Timbre,* Project for Music Experiment, University of California, San Diego, 1974.

## James A. Moorer

**BORN:** November 25, 1945, in Hollywood, Florida.

**EDUCATION:**

Musical studies: Florida State University, 1962-63; Boston University, 1966; M.I.T.,1967.
S.B. (Electrical Engineering) M.I.T., 1967.
S.B. (Applied Mathematics) M.I.T., 1968.
Ph.D. Candidate (Computer Science) Stanford University,
dissertation: *On the Segmentation and Analysis of Continuous Musical Sound.*

**PROFESSIONAL EXPERIENCE:**

Jazz Guitarist, 1964-1966
Systems Programmer, Education Research Center, M.I.T.,1966-68.
Head of Systems Programming, Stanford Artificial Intelligence Laboratory, 1968-72.
Research Assistant, Stanford Artificial Intelligence Laboratory, 1972 to present.

**PUBLICATIONS:**

*Music and Computer Composition,* Communications of the ACM, Vol.15,2,1972.
*The Optimum Comb Method of Pitch Period Analysis of Continuous Digitized Speech,* Stanford Artificial Intelligence Laboratory Memo 207, July 1973. Accepted for publication in the IEEE Transactions on Acoustics, Speech, and Signal Processing.
*The Heterodyne Filter as a Tool for Analysis of Transient Waveforms,* Stanford Artificial Intelligence Laboratory Memo 208, July 1973.

**PUBLIC LECTURES:**

*On the Digital Signal Processing Aspects of Computer Analysis and Synthesis of Music Instrument Tones,* Carnegie-Mellon University, 1973.

## Loren Rush

BORN: August 23, 1935 in Fullerton, California.

EDUCATION:

B.A. (Music) San Francisco State University, 1957.
M.A. (Music) University of California, Berkeley, 1960.
D.M.A. (Doctor of Musical Arts) Stanford University, 1969.

AWARDS AND FELLOWSHIPS:

George Ladd Prix de Paris Scholar in Music, 1960-62.
Fromm Music Foundation commission, Tanglewood, 1964.
First mention, Royaumont International Composition Competition, France, 1965.
Various graduate fellowships, Stanford University, 1966-69.
Rome Prize Fellowship, American Academy in Rome, 1969-71.
Prince Pierre of Monaco Musical Composition Award, 1971.
John Simon Guggenheim Memorial Fellowship, 1971.
National Institute of Arts and Letters Award, 1971.
San Francisco Symphony commission, 1973.
National Endowment for the Arts Fellowship Grant, 1974.
San Francisco Symphony-National Endowment for the Arts Bicentennial Commission, 1974.

PROFESSIONAL EXPERIENCE:

Associate Music Director, KPFA-FM, Pacifica Foundation radio, Berkeley, Calif., 1957-60.
Instructor of Music Composition and Theory, San Francisco Conservatory of Music, 1962-67.
Organized and directed Performer's Choice, performance group, 1963-65.
Organized and directed the San Francisco Conservatory Artists Ensemble, 1966-69.
Member, Computer Music and Acoustics Group, Stanford, 1966-69.
Acting Lecturer in Music, Stanford University, 1967-68.
Chairman, Composition Department, San Francisco Conservatory of Music, 1967-69.
Visiting Scholar, Stanford Artificial Intelligence Laboratory, 1971-present.
Composer in Residence, San Francisco Symphony Orchestra Summer Music Workshop, 1973.

PUBLICATIONS:

*Nexus 16* for chamber orchestra, Editions Jobert, Paris, 1966.
Recorded for Wergo (Germany) by the San Francisco New Music Ensemble, 1971.
*Oh, Susanna* for piano, Editions Jobert, Paris, 1972.
*String Quartet in C# Minor,* in press, Editions Jobert.

MAJOR PERFORMANCES:

*Dans le Sable,* Rome Symphony Orchestra, Ferruccio Scaglia cond., Rome, 1970.
*Nexus 16,* Lincoln Center Ensemble, Dennis Russell Davies cond., New York, 1972.
*The Cloud Messenger,* San Francisco Symphony Orchestra, Seiji Ozawa cond.,
San Francisco, Leningrad, Vilnius & Moscow, 1973.
*I'll See You in My Dreams,* San Francisco Symphony Orchestra, Niklaus Wyss cond., S.F.,1973.