AN INTRODUCTION TO THE COMPOSITION AND GENERATION OF COMPUTER MUSIC

by

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PREFACE

The purpose of this report is to give a general introduction to computers and their usage as a medium for composition and generation of sound. Chapters include an Introduction to Computers, Computer Composition, Computer Generation of Sound, Methods of Computer Generation of Sound, Technological Advancements and Experiments, and the Future of Computer Music. The report is not intended to be an inclusive study of all of the equipment, programs, and languages that have been or are being developed at this time. Developments in hardware (machines) and software (programs and languages) over the past decade have continued at a rapid pace. These developments are numerous and are happening simultaneously throughout the world; many of them are the results of experimentation completely independent of computer music. Researchers are hampered in identifying and explaining the numerous and rapid developments because of communication problems between experimenting individuals. Many accounts of systems are recorded in unavailable, or difficult to obtain, laboratory and technical reports.

The experiments and developments discussed in this paper were chosen because of their direct bearing on the computer composer. Most of these simplify the composer's task and enable him to devote more concentration to the composition of music. With a few exceptions, this report deals with studies and developments prior to 1970 in the United States. The author makes no attempt to evaluate which program, language, or equipment is superior. Each has its own purpose, and each individual must choose the hardware and software which best suits his needs and the capabilities of his equipment.

The author wishes to express his gratitude to Professor Hanley Jackson, Department of Music, Kansas State University, for numerous and invaluable suggestions and criticisms.

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CHAPTER I

INTRODUCTION TO COMPUTERS

A computer is a device which receives information, acts upon it, and furnishes results in a form to be read by either a human being or by a machine. There are two basic types of computers, analogue (or analog) and digital. Both of these can perform mathematical operations and store data for later use.

An analog computer represents variable quantities that are to be manipulated by electrical quantities. These machine quantities are said to be analogous to the actual quantities; hence the name "analogue." The variable quantities in a digital computer are represented by numerical codes, usually in the binary number system. Physical properties of music lend themselves to digital computation and therefore analog computers will not be discussed.

The origin of electronic digital computers can be traced back almost 2,000 years to the abacus. This was the first device invented by man to express specific quantities. During the seventeenth century Blaise Pascal of France invented a gear-driven machine the size of a shoe box which served as an adding machine. Charles Babbage, an Englishman, in 1822 designed a "difference engine," that would do complex calculations and print out the results. However, technology at that time was not sufficient and it was not until one hundred years later that the machine could be constructed.

The first electromechanical system for recording, compiling, and tabulating digital data was constructed in 1887 by Herman Hollerith, a New York statistician. The system was used by the United States Government to help compile the 1890 census. Basically the system read punched cards and recorded the number of holes present. This card system is the forerunner of the present day Hollerith card or punched card.

The first electronic digital computer using vacuum tubes rather than electric relays was the "Electronic Numerical Integrator and Computer" (ENIAC). It was developed at the University of Pennsylvania in 1946. In 1951, UNIVAC, the first computer for commercial application was built. Computer improvements during the 1960's have been characterized by increased speed and decreasing size and cost. The electron tubes used in the early electronic computers were replaced by semiconductors, such as transistors, and these in turn gave way to the integrated microelectronic circuits.

A digital computer is composed of four large sections: input devices, storage devices, the central processing unit, and output devices. Digital information, or data, is fed to the computer where it is converted into a series of electrical impulses. These are then processed according to instructions stored in the machine's "memory." The result of this processing appears as some form of output.

The technique of instructing the computer to perform various operations is called "Programming." A program defines in complete and minute detail what the computer is to do under every conceivable combination of circumstances with the data that is subsequently fed into it. This program is then stored in the system's "memory" in the proper sequence for later response.

A central processing unit consists of a control section, and an arithmetic-logical section. The control section directs and coordinates all operations that are called for by the program. The arithmetic-logical section adds, subtracts, multiplies, divides and compares numbers at rapid speeds. The digital computers of today are capable of performing up to 10,000,000 or more operations per second. It should be noted that even though digital computers are reaching phenomenal speeds, the accompanying equipment needed for the generation of sound has not been able to match this high speed computation.

It is not within the scope of this paper to define all of the developments in the lineage of computers. Developments in both equipment and programs have progressed at a phenomenal pace during the past decade. People working with computers have to face the challenge of maintaining the flexibility necessary to move with rapid change and not become tied to outmoded systems.

CHAPTER II

COMPUTER COMPOSITION

The range of possibilities for the twentieth century composer is wide open. The composer may use the computer to write music which will be played by musicians using conventional instruments and conventional notation. He may use the computer to expand our present day musical system by developing new sounds or new compositional devices. Regardless of the procedure chosen, the many possibilities available pose a challenge to his imagination as well as to his technical skill.

Probably for certain musicians it will be surprising to learn that melody obeys fixed rules, laws and principles of logical development. Generally, a nineteenth century romantic notion likens melody as being composed in a surge of inspiration, by a single act, unconsciously, and not according to some specific set of rules and laws. At times, even the composers themselves find it difficult to explain certain features of their styles that are particularly characteristic. In actuality, laws and rules for the construction of musical works and principles do exist; application of these in the creative process are made sub-consciously, intuitively.

In the 1950's a technique was developed for writing music by means of automatic computers such as the ILLIAC, located at the University of Illinois. The technique depends first of all on numbering consecutively the notes of the musical scale. This permits the rules of musical composition to be expressed in terms of mathematical operations suitable for computer use.

Some of these rules were set down by Zaripov in an article entitled "Cybernetics of Music."[1] They are:

> 1. All sounds of melody are broken up into groups placed one after the other, and in each of these groups one sound is stronger and all the others are weaker.
> 2. In most melodies, the number of notes going in one direction does not exceed six. Although exceptions are encountered.
> 3. The sum of two adjacent intervals during movement of the melody in one direction (up or down) does not exceed an octave. Also--along with wide intervals of the melody goes a small number of notes. If in the one direction there are more notes, then the interval between them are smaller, narrower.
> 4. The repetion [sic.] of rhythmic and melodic figures is a law of structure and is always encountered in such melodies.
> 5. Some tones of a scale are more stable than others.

Secondly, a computer can be programmed to generate successively, at a very rapid rate, random numbers which may now be thought of as the notes of random music. The basic technique is to place restrictions upon random number generation so that the number of choices is reduced to those which do not violate the musical rules in effect. ". . . the more order we wish to impose, the more restrictions we have to make in composition. The more limited the style, the more we must consciously reject."[2]

Among the early experiments in computer composition were those of Lejaren Hiller and a mathematician, Isaacson, at the University of Illinois in 1955. They programmed, on the ILLIAC computer, the composition of a suite for string quartet. This piece was later called Illiac Suite for String Quartet and was publicly performed at a University concert toward the end of 1956.[3] The suite consisted of four parts, corresponding to the number of

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[1] R. Kh. Zaripov, "Cybernetics and Music," Perspectives of New Music (Spring-Summer, 1969), p. 123.

[2] Lejaren A. Hiller, Jr., "Some Structural Principles of Computer Music," Journal of the American Musicological Society, IX (Fall, 1956), p. 247.

[3] A recording of a complete performance by the University of Illinois Composition String Quartet is available from M.G.M. Records, "Computer Music from the University of Illinois," 12", LP, Heliodor, H/HS-25053, 1967.

groups of experiments.

The aim of the first two sections or experiments was to put together a simple two-part and four-part piece in the key of C major. The sequence of notes and chords was obtained as a result of a selection from a sequence of random notes with the aid of several rules. These rules were from the rules of part writing in the sixteenth century. The range of the melody began on middle C, none of the succeeding intervals exceed an octave, and third and sevenths were ruled out. A simple rhythmic pattern was set up beforehand and repetition of the phrase was taken into account. The rules of counterpoint and part writing, in particular the fixed forms of cadences, the ending of phrases, and the ban on parallel fifths and octaves were also considered.

The music of the third movement was constructed according to the same rules with the addition of sharps and flats, indication of tempo, dynamics, and articulation. Zaripov states that in his opinion the music is similar to the style of the Atonal composers of the twentieth century.[4]

The fourth movement was synthesized exclusively according to mathematical rules based on a formula completely abstract from music. The selection of sequences of notes and chords was carried out in accordance with the Markov table of random numbers, which has no relation to music.

Other experiments were conducted in 1956 by Klein and Bolitho of Electro Data, a division of the Burroughs Corporation at Pasadena, California. In accordance with the simple rules of composition, sequences were selected from various random combinations of notes. They obtained four thousand songs which were recorded and broadcast over the radio under the name of "Push Button Bertha."[5]

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[4]Zaripov, "Cybernetics and Music," p. 124.

[5]Ibid.

A clear picture of computer composition is given by S. Gill in "A Technique for the Composition of Music in a Computer."[6] This paper describes the principal features of a Pegasus computer program that was written to generate music in the style of Schoenberg. It must be kept in mind that this music has to be transcribed by man into notation and played on conventional instruments. In this case Mr. Lionel Salter acted as musical advisor, translator and arranger for the computer output. Again, the procedure is to set up a routine that will generate random numbers, obeying as many rules as possible. Then by subsequent scanning, it rejects those which violate the remaining rules, and keeps the ones that have the most desirable features. It is not practical to generate the complete composition without scanning in stages.

The rules that were used for the Pegasus program allowed for three voices in $\frac{3}{4}$ time, and no notes shorter than an eighth note. The following were also taken into consideration:[7]

1. Each voice was constrained to follow the twelve degrees of the octave in a particular sequence. (tone row)
2. The length of each note and the appearance of rests was open to choice.
3. The same series of twelve degrees was repeated throughout the work although on each appearance it could be transposed up or down by any amount, reversed, inverted, or individual notes could be transposed up or down by a complete octave.
4. A row could jump from one voice to another.
5. Each voice should rest for about a bar roughly once in every four or five bars, but preferably no two voices should be resting at the same time.
6. Of the active voices, one should be moving fairly rapidly and the others more slowly.
7. Control over the length of skips in each voice.
8. Avoidance of parallel octaves or near octaves.
9. Range of two octaves.

In this composition no attempt was made to provide an overall structure.

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[6] S. Gill, "A Technique for the Composition of Music in a Computer," Computer Journal, VI, 2 (July, 1963), p. 129.

[7] *Ibid.*, p. 130.

The computer was not programmed to produce a satisfactory ending. Pegasus simply generated a measure or two more than required and the composition was trimmed to length later. The main difficulty with this process is that in using random generation of notes the computer can write itself into a dead end. It may create a sequence of tones that, when later applied to the rules of composition, will violate those rules. It is therefore desirable to have some way for the computer to back-track immediately.

The technique adopted in the Pegasus program was to retain at any given moment not one but eight competitive versions of the melody. All of these versions were complete in themselves but not necessarily of the same length. The computer would take each of the eight sequences and at random, add a note of eighth note duration to it. Then the scanning process takes over and the weakest sequence rejected, and the whole process starts again. The sequences were represented in the machine in the form of a tree, each sequence being linked backwards in time from the end to the beginning. The result of this procedure was that the composition grew like a gree, continually growing new branches which grew according to how successful they were in meeting the rules. The longest continual branch was taken as the final composition and trimmed to length. Figure 1 shows the first one hundred steps in the development of a composition by this process. The heavy line shows the sequence that was retained for the final composition.[8]

The output notation of the computer was restricted by the teleprinter available. Pitches were indicated by extending the usual nomenclature A to G to cover the second octave. A' was H, B' was I, and so on. Accidentals were indicated by a sign $, meaning sharp. Flats were unnecessary because in this music no distinction is made between A and G#. Inside the computer, pitches

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[8] _Ibid._, p. 131.

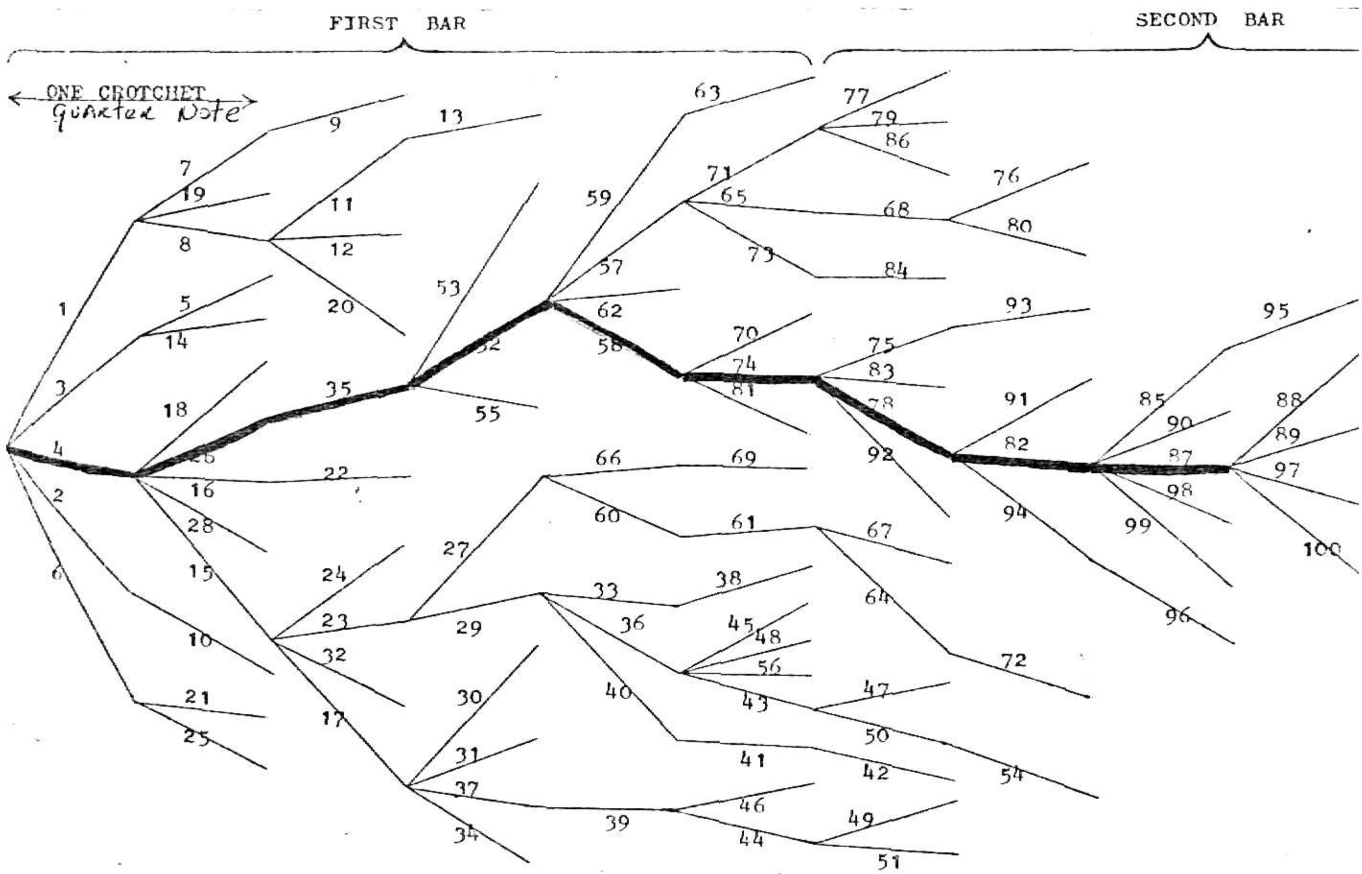

Fig. 1

were represented by the number of semitones above a base pitch. For output a mathematical equation was applied to the number, resulting in a letter. The integral part of the number gave the letter, and the size of the fractional part showed whether a sharp was needed. Two printed characters were allowed per eighth note. The holding of a note for more than an eighth note is shown by a line of dots. Rests are indicated by the letter 0 and each voice is represented by one of the three lines of print. The reader will notice that there are twelve character spaces in each group. Taking two characters for each eighth note, there are six eighth notes indicated in each group and therefore a time signature of $\frac{3}{4}$.

Computer Printout:[9]

B.GF..O.E.	D.H$J.K.....	L.N.I.O.M$O.
FAC$..F.A.	O.J.K.N...I.	D.E.MNH$..
O.O.O.O.G.L.	J...O.O.O.O.	O.O.O.KG..

Fig. 2

This printout was then translated into a conventional score. Part of the composition is shown in Figure 3.[10]

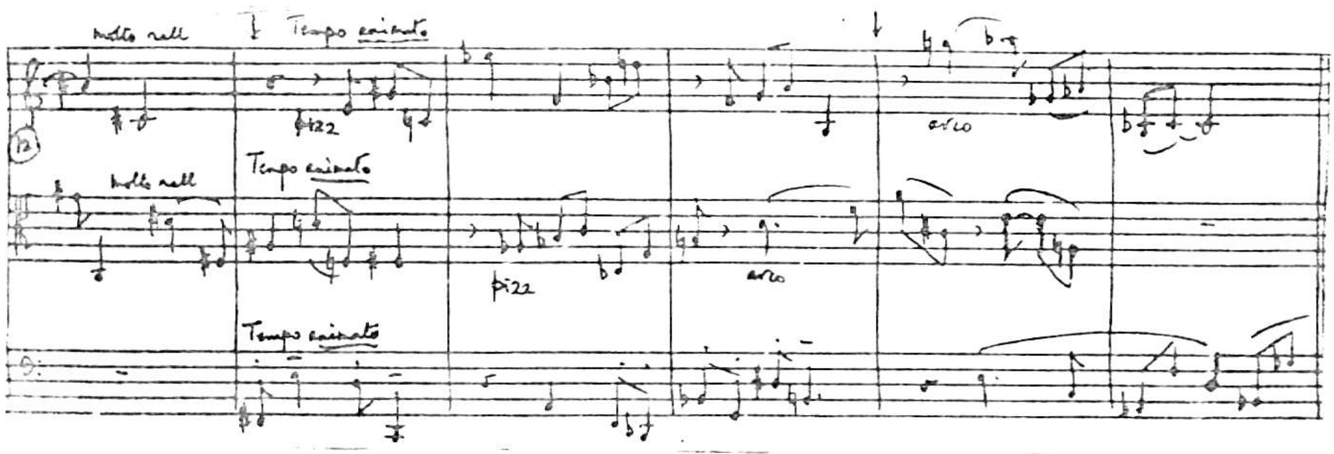

Fig. 3

The use of a computer for composition gained some prominence circa 1958.[11] As has been shown, the output of computers used for composition is either a digital tape or a printout containing information which represents sound. These numbers or letters had to be translated into musical symbols and played on conventional instruments. The time consumed in preparing the program and transcribing the output notation was very long. The use of computers solely for composition was therefore impractical.

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[9] Ibid., p. 133.

[10] Ibid., p. 129.

[11] Albert Seay, "The Composer of Music and the Computer," Computer and Automation, XIII, 8 (August, 1964), p. 16.

CHAPTER III

COMPUTER GENERATION OF SOUND

A program, or set of instructions, for the computer generation of music is more complex than a program for composition alone. Computer generation of music refers to the process of converting a set of numbers into sound. These numbers will precisely describe the parameters of pitch, duration, loudness, attack, etc., and may be derived from conventional scores or may be the result of computer composition routines. A single note, middle C for instance, must have in its description frequency in cycles per second, duration in time, attack and decay called "envelope," dynamic level in decibels, and timbre usually described by being played on a certain instrument.[1] This description of the note is inserted into the computer in one of several ways. Input can be furnished by punched paper tape, punch cards, typewriter, or some type of music reader. The composer, by inserting information through one of these means, can specify parameters to be specified by the computer.

Punched paper tape is a continuous strip of paper on which round holes are punched. The tape is punched by a special typewriter that punches a particular pattern of holes for each character typed. The paper-tape reader, attached to a computer, senses the pattern of holes photoelectrically and records the character in the computer memory. A tape reader can commonly read 1,000 characters per second.

The most widely used type of input at the present time is the punch

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[1]The term "instrument" in computer generation refers to a combination of unit generators which produce a certain characteristic sound.

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card or Hollerith card. The common card is divided into eighty columns each with twelve punch positions. The cards are prepared with a key-punch or a typewriter attached to a key punch. A typical note card is shown in Figure 4.[2] This note card states the duration in seconds, the intensity in decibels

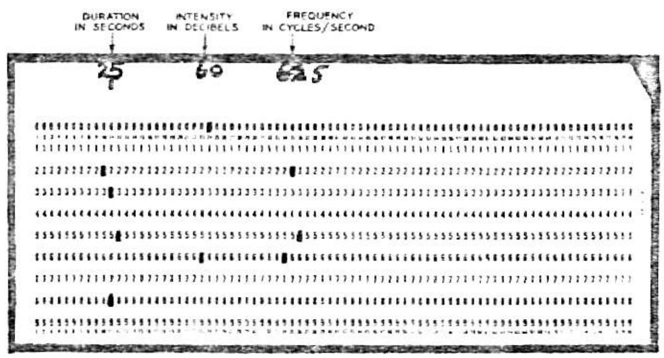

Fig. 4

and the frequency of the pitch in cycles per second. Usual reading speeds are between 600 and 1,000 cards per minute.

> There have been exhaustive discussions as to the relative merits of cards and paper tape as computer input media. . . . Considerations relevant to a particular firm or organization usually determine the choice.[3]

Another type of input device is the typewriter. Most computers have a typewriter that is directly connected to the computer memory which can be used for the insertion of instructions or data. These are usually standard electric typewriters or teletypewriters. However, the composer must learn the "code" for these or employ a skilled computer operator, and these machines are mainly used when a rapid response is needed. One newer innovation is the

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[2] James C. Tenney, "Sound Generation by Means of a Digital Computer," Journal of Music Theory (Spring, 1963), p. 29.

[3] Peter C. Sanderson, Computer Languages: A Practical Guide to the Chief Programming Languages (London: Newnes-Butterworths, 1970), p. 5.

music typewriter which types directly in musical notation. This will be discussed in more detail later.

The Graphic Input Computer, Graphic-1, is a newly developed device for feeding musical notation to the computer. The composer draws his music on the Graphic-1 console. This system converts graphic images to the computer program, MUSIC IV. This, then, results in a digital tape which is fed into the main computer. The Graphic-1 system seems to be one of the most valuable advancements in the technology of input systems for the composer. It will be discussed in more detail in Chapter V.

The primary principle in computer generation of sound is fairly simple. "Any sound, no matter how complex, can be represented by a single-value function of pressure versus time."[4] However, the variations in air pressure that constitute a sound wave are continuous functions of time, whereas the digital computer can only deal with non-continuous numbers. The computer is therefore programmed to record instantaneously the height of a particular wave form at equally spaced intervals. This process is called sampling. As a result of this sampling process any acoustical signal can be specified in numerical fashion by a sequence of discrete amplitude samples. Figure 5 shows how a computer samples a simple wave form. It has recorded the amplitudes at seventeen points which are equally spaced.[5] The time interval between successive samples has to be short enough to accurately give a true picture of the wave form. This sampling rate depends on the bandwidth of the signal. To adequately specify a sound wave containing frequency components no higher than some upper limit "F" cycles per second, a sampling rate of at least "2F"

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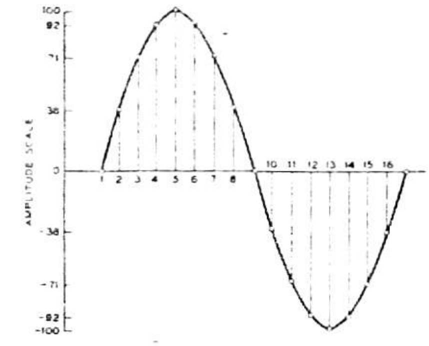
[4]J. L. Divilbiss, "The Real-Time Generation of Music with a Digital Computer," <u>Journal of Music Theory</u> (Spring, 1964), p. 100.

[5]Tenney, "Sound Generation," p. 28.



SAMPLE NUMBER	AMPLITUDE
1	0
2	38
3	71
4	92
5	100
6	92
7	71
8	38
9	0
10	-38
11	-71
12	-92
13	-100
14	-92
15	-71
16	-38
ETC	

Fig. 5

samples per second is required. Thus, a signal with a bandwidth from zero to 10,000 cps would require a sampling rate of 20,000 samples per second.[6] Obviously, it is only because of the enormous speed at which the modern computer can perform these calculations that this sampling process becomes a relatively practical way of generating sound.

The output capabilities of the computer resemble the input devices. The output can be punched tape or cards, line print, typewriter, graph plots, or cathode-ray tube (CRT) displays. Punched cards and tape output are the same as input; the most common of the two is tape which can be read by a computer or used on a tape-controlled typewriter to give printed output. A typical punch speed is 110 characters a second. Paper tape is almost exclusively used when the output from the computer is only an intermediate step because of the digital-to-analog processes involved. Paper tape is also the most durable and compact for storage and later use.

The line Printer prints a line of type at a time. Printing is done on continuous stationery. Average printing speeds are between 600 and 1,000 lines per minute with 120 characters per line.

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[6] <u>Ibid.</u>, p. 29.

Typewriters that are used for output are the same as those used for input. Their relatively slow speed causes them not to be used for large amounts of data.

Graph plotters and CRT displays visually show the output data. The Graph plotter is a digital-increment plotter which can be attached to a computer. It produces graphs or drawings from coordinates within the computer. A common form of this device consists of a movable pen and paper rollers that move under computer control. CRT displays can be used to display data either in character form or graphs and drawings.

A sample of a digital output tape of the computer process so far can be seen in Figure 6. Each of the samples appears as a binary number, (+0100110)

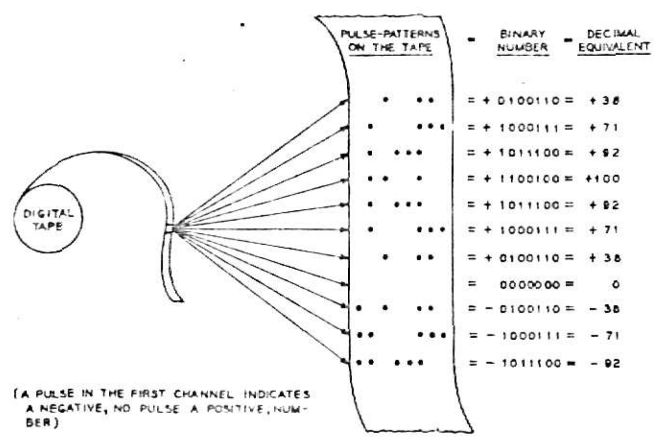

Fig. 6

which is represented by the positive dot on the tape for + or 1, and the absence of a dot for - or 0.[7]

This output tape must next be made to determine a continuous pattern of magnetization on ordinary recording tape. This is done by a digital-to-

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[7] Ibid., p. 31.

analog conversion device called a "Data-Translator" or "Digital-to-Analog Converter."[8] This machine converts the numerical output of the computer into an electrical pulse whose amplitude or voltage is equal to the size of the number. This concept may be made clearer by drawing an analogy with a phonograph record, a needle, cartridge, audio amplifier, and speaker. The record groove walls contain minute wrinkles or complex waves which force the needle to move irregularly within the magnetic field of the cartridge. These variations in the walls are much like the numerical variations on the output tape. The continuous movement of the needle within the cartridge gives the same effect as the digital-to-analog converter does in changing the numerical fluctuations into fluctuations in electrical current, which when amplified produce audible sound waves.

At present only a few computer installations for the general user in the United States have any facility for converting audio signals into corresponding digital data and for the reverse operation of converting digital data into audio signals. James W. Beauchamp, an Associate Professor of Music and Electrical Engineering at the University of Illinois, states several reasons for this state of affairs:[9]

> 1. The operation of A/D equipment requires special procedures.
> 2. The high sample rates and high quantization accuracies required for audio work have not been achievable until recently.
> 3. The number of potential users of such A/D and D/A facilities is small compared with the total population of computer users.
> 4. The use of analog signals has not been part of the research interests of the people who make computer usage policy.

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[8] Some people refer to this machine as a digital-to-analog converter, others as a data translator. Digital-to-Analog is usually referred to as D/A and the reverse process, Analog-to-Digital, as A/D.

[9] James W. Beauchamp, "A Computer System for Time-Variant Harmonic Analysis and Synthesis of Musical Tones," Music by Computers, ed. by H. Von Forester and James W. Beauchamp (New York: John Wiley and Sons, 1969), p. 23.

In recent years technology has improved to the point at which an A/D-D/A converter system with the necessary speed (20,000 to 50,000 samples per second) and quantization accuracy can be purchased for $4,000 to $8,000. Conversion equipment is now connected to computers at Bell Telephone Laboratories in Murry Hill, New Jersey, M.I.T., Brooklyn Polytechnic Institute, The University of Illinois, Stanford, and U.C.L.A.[10]

After D/A conversion the sequence of electrical pulses is directed through a low-pass filter with its upper cut-off frequency set at half the sampling rate. This smooths out the signal and it may then be fed directly into an amplifier for realization. The smoothed out signal might also be recorded on magnetic "analog" tape. This can be played back at a later time by conventional tape recorders and loudspeakers. A diagram of this process appears in Figure 7.[11]

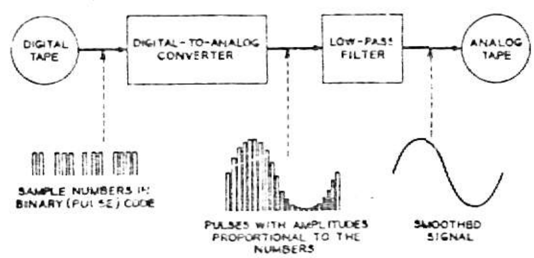

Fig. 7

It must be noted that the computer itself does not generate sound. It is the data-translator that produces the sound in conjunction with the low-pass filter and amplifier. It must also be noted that the preceding description of computer generation dealt with only one parameter of sound, pitch. Each one of the parameters must be dealt with simultaneously to obtain a total composition.

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[10] Ibid., p. 24.

[11] Tenney, "Sound Generation," p. 31.

CHAPTER IV

METHODS OF COMPUTER GENERATION OF SOUND

The most significant and powerful approach to computer music generation is the method devised by Max V. Mathews of Bell Telephone Laboratories. This system basically involves:[1]

1. Statement by the composer of the score and characteristics of the "instruments" employed.
2. Calculations of the sample points by the computer.
3. Transfer of the tape to the digital-to-analog converter where it is read and converted to sound.

It is only at the last stage of this sequence that the composer actually hears the results. If he is to modify any part of the score or the character of any instrument, he must repeat the entire sequence using the new material. These modifications may occur frequently since it is often difficult to give an accurate description of even the most familiar sound. The user is reduced to trial and error approach with a large delay between modification and the actual sound. This lack of immediacy is a limitation of the BTL system. Besides the lack of immediacy, the time required to compute normal music is ten times that of its performance. For example: a sound which is the sum of several voices has a corresponding number of different waveforms, envelopes, and amplitudes. Under these conditions the computer can only sample at the rate of 1,000 samples per second and therefore it would take ten seconds of computer time to reproduce one second of sound.

Another limitation of the BTL system is cost. Generation of music is

[1] J. L. Divilbiss, "The Real-Time Generation of Music with a Digital Computer," Journal of Music Theory (Spring, 1964), p. 103.

impractical on any except a large, high speed machine and the cost of actual running time is approximately $500 per hour.

At the University of Illinois, the Consolidated Science Laboratory has constructed a simple computer-based music system which was intended to minimize the cost and immediacy. The system is known as CSL and is used on a CSX-1 computer. This is a special-purpose machine especially designed for real-time input/output communication and logical manipulation of data. The CSX-1 has sixteen levels of interrupt but no direct-memory access. This computer is of modest size and speed, thus the cost of operating is said to be one-hundredth of the cost of the BTL system. The cost comparison is based on the cost per minute of music, rather than hourly charge for the use of the computer.

In the CSL system, musical sounds are produced while the computer is operating rather than after the completion of the program. The computer is said to operate in real-time if it supplies information more or less continuously during its operation. This real-time generation allows the composer to stop the machine at any point within a matter of seconds. This is possible because of automatic call-up of computer sub-routines.

Like the BTL system, CSL has its limitations. Because of its simplicity, it can generate a wide variety of sounds; however, it cannot create all mathematically describable sounds. Another limitation is the inability to adjust envelope and timbre automatically. This is unfortunate since most instruments change timbre in their different registers and composers like to use different envelopes for variation.

The composer's task, as was said, is more complicated in computer composition. Preparing a score or program for the computer differs from conventional scoring chiefly in the degree of explicitness required. Every musical event must be described exactly in terms of pitch, loudness, and duration. This becomes very difficult and complex since conventional notation relies on descriptive phrases such as allegro, forte, ritard, etc. Numerical equivalences do not readily come to mind for these phrases. In computer music the composer assumes the additional role of the performer since the subtleties of interpretation can come only from the numbers entered into the computer at the beginning. This is a difficult process; however once acquainted with the computer, the machine itself can be used to simplify this process.

The composer uses a whole new language in computer composition. He must have a working knowledge of FØRTRAN IV. This computer language is used because it can easily be modified for use on a variety of computers. The most important music program written is MUSIC V, which is a direct descendant of MUSIC IV. MUSIC IV was rewritten in MUSIC V so it could be used on a more advanced computer. The following is a simple explanation of MUSIC V program using FØRTRAN IV.

The term "orchestra" or "instrument" refers to a generator of some sort. It also could be a group of generators of a characteristic sound. This becomes as familiar to the computer composer as the sound of an oboe or trumpet is to the conventional composer. The score is the list of numbers which are put into the computer for computation. Each line of the score is called a "record."

Figure 8 shows a conventional music score of the music to be represented by the computer.[2] It is the first two measures of the song "Lilly Marlene." The reader will notice that the tempo marking is a quarter note equals sixty.

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[2] Max V. Mathews, The Technology of Computer Music (Cambridge: Riverside Press, Inc., 1969), p. 45.

Fig. 8

This means one quarter note per second. It should also be noted that there are eleven notes in the score. There are two different articulations shown: staccato and tenuto. There are also two crescendi and one decrescendo.

Figure 9 shows a block diagram of a simulated instrument that will play

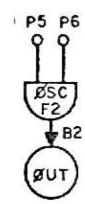

Fig. 9

the music.[3] It consists of an oscillator, marked ØSC, and an output box marked ØUT. The oscillator has two inputs. P5 is the amplitude or loudness of the output and P6 is the frequency or pitch of the sound to be generated. The wave form of the oscillator is determined by a previously stored function, represented by F2. This wave form is shown in Figure 10.[4] The amplitude is shown by the distance above or below the base line. The horizontal line is time in milliseconds, and the dotted lines show sample points. It must be noted that at some time in the process this wave form must be completely defined for the computer.

The computer score is shown in Figure 11.[5] Each of the records has

[3] Ibid.

[4] Ibid.

[5] Ibid.

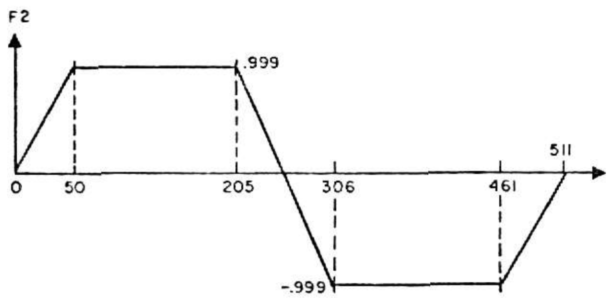

Fig. 10

```
 1  INS 0 1 ;
 2  ØSC P5 P6 B2 F2 P30 ;
 3  ØUT B2 B1 ;
 4  END ;
 5  GEN 0 1 2 0 0 .999 50 .999 205 -.999 306 -.999 461 0 511 ;
 6  NØT 0 1 .50 125 8.45 ;
 7  NØT .75 1 .17 250 8.45 ;
 8  NØT 1.00 1 .50 500 8.45 ;
 9  NØT 1.75 1 .17 1000 8.93 ;
10  NØT 2.00 1 .95 2000 10.04 ;
11  NØT 3.00 1 .95 1000 8.45 ;
12  NØT 4.00 1 .50 500 8.93 ;
13  NØT 4.75 1 .17 500 8.93 ;
14  NØT 5.00 1 .50 700 8.93 ;
15  NØT 5.75 1 .17 1000 13.39 ;
16  NØT 6.00 1 1.95 2000 12.65 ;
17  TER 8.00 ;
```

Fig. 11

been numbered for reference in this discussion. Each record or line has a sequence of entries. Up to thirty entries may be used for any one record. Entries are separated either by a comma or a blank space. In this score the blank space is used. The record is ended with a semi-colon. A record may extend over several lines or even two records on one line. In the following example, record #2 has been broken down into entries for clarity.

```
Entry     #1   2   3   4   5   6    End of record
Record    ØSC  P5  P6  B2  F2  P30  ;
```

In the computer score, Figure 11, records 1 through 4 define for the computer the instrument shown in Figure 9. INS 0 1; says that at time 0 in the composition, instrument 1 will be defined. Record 2 says that the first unit generator in the instrument will be an oscillator, ØSC. It will have inputs P5 and P6 which have been previously stored in the memory bank. The output will be stored in I-Ø block B2 and finally it will use P30 for temporary storage.

Record 3 states to take the sample of I-Ø block B2 and add them to the contents of block B1 in preparation for output. B1 could be another complete instrument or the addition of vibrato to the instrument B2.

Record 4, End; terminates the instrument definition.

Record 5 defines the function F2, Figure 10, and causes it to be generated and stored in the computer memory assigned to F2.

Records 6 through 16 show the notes 1 through 11 in the score in their proper order. In each of the records entry 1 (NØT) states the purpose of the record is to play a note. Entry 2 gives the starting time of the notes measured in seconds from the beginning of the composition. The note in record 7 starts at .75 seconds after the beginning. Entry 3 gives the instrument number on which the note will be played. In this case all will be played on instrument number 1. Entry 4 gives the duration of the note in seconds. This point is very important because it affects the length of the note to be played such as a quarter or eighth note, as well as the articulation of the note. Staccato notes are written to produce more silence between successive notes than the legato notes. Example: record 7, entry 4, is .17 seconds. This refers to note 2 of the conventional score, a sixteenth note. Record 10, entry 4, is .95 seconds, equaling a quarter note with a tenuto marking. The quarter note is note 5 in the conventional score.

Entry 5 gives the amplitude of the note as required by the instrument. In this "training orchestra" (sample composition shown in Figure 11) the amplitude can vary over a range 0 to 2047. The amplitude is varied to correspond to the dynamic markings on the conventional score. The reader can see this number increase from 125 in record 6, to 2,000 in record 10. This increase corresponds to the crescendo marking.

Entry 6 is the frequency of the pitch. The number is derived by multiplying .02555 times the frequency of the note in cps. A mathematical constant, .02555, is derived from the equation:

$$\frac{511}{20{,}000 \text{ (Sampling rate) X note duration}}$$

Record 17 terminates the composition at 8 seconds.

CHAPTER V

TECHNOLOGICAL ADVANCEMENTS AND EXPERIMENTS

Several experiments and advancements in technology have made available new hardware and software useful for the composition of computer music. Musical Keyboards as input devices would seem to be the easiest way in most cases to communicate; however, they have not achieved success. Keyboards have been widely used to control analog circuits and voltage-controlled oscillations; however, digital installations have not been attempted.

Automated Music Printing

R. A. Baker and Lejaren Hiller have been experimenting with automated music printing. They have reconstructed, along with Cecil Effinger and Robert M. Oliver of the University of Colorado, a commercially available typewriter equipped with a punch card or paper tape unit. Effinger designed the Music Writer, a manual rebuilt R. C. Allen typewriter, incorporating into it a number of mechanical changes. He also equipped it with musical typeface. A program was then devised so that the Illiac computer could store the music in the form of a binary input tape.

Hiller and Baker state several disadvantages for data preparation:[1]

1. It is not notably faster than hand copying.
2. Its repertory of symbols is limited even with a double keyboard system.
3. It is restricted in terms of spacing and symbol size.

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[1] Lejaren A. Hiller, Jr. and R. A. Baker, "Automated Music Printing," Journal of Music Theory (Spring, 1965), p. 135.

4. It does not supply slanted symbols such as slanted slurs, glissandi, etc.
5. It is difficult to keep precisely in perfect working order because of highly restrictive spacing tolerances.

They suggest its primary advantages are the relatively simple design, ease of use, and moderate cost.

Music Editor

Hiller states that newer devices such as the Cathode-ray tube and photographic displays are much more flexible and versatile in terms of spacing, size of symbols, and repertory of symbols than anything achievable by means of typewriters or related devices. One very important advance in technology is the introduction of a Music Editor. A Music Editor enables one to enter music into a computer memory using conventional notation.

Programs that accept and play back common musical notation have been developed by W. B. Barker and Don Cantor at Harvard University. The programs are used on a PDP-1 computer with four display oscilloscopes. Cantor's system is an elaboration of Barker's which accommodated monophonic music. It could only deal with melodies. Cantor's system works with two voiced polyphony. The conventional notation is displayed on the face of a Cathode-ray tube, as shown in Figure 12.[2] The symbols and instructions are deployed on the staff by the use of a stylus or light pen held by the operator. The stylus is moved over a grid of 1,000 x 1,000 fine wires covered by a 10" x 10" tablet in front of the display scope. The computer samples the stylus position and senses where the notes are to be placed on the staff. The stylus is also used to select commands from the repertoire of eight in the two columns directly beneath the symbols. The commands instruct the machine to move lines from one

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[2]Don Cantor. "A Computer Program that Accepts Common Musical Notation," Computers and the Humanities (November, 1971), p. 103.

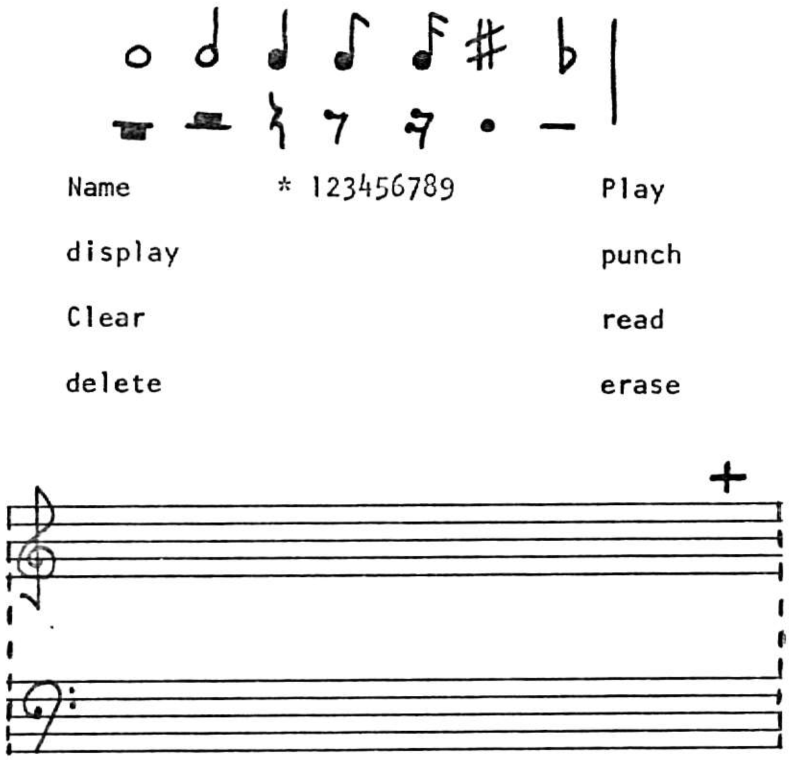

Fig. 12

scope to another, to permute and combine the lines into pieces of music, to punch the music on tape, to retrieve them later by reading the tape, to display them on the scopes, or finally, to play them.

The composer starts the process by typing "Start Music" on the Teletype which is attached to the PDP-1 computer. The computer then displays the material in Figure 12 on one of the four oscilloscopes. This scope is called the "workscope," the musical symbols are the "menu," and the list of words are called the "commands." The remaining scopes each have two staff braces. These are used to display music already notated.

The composer starts the program by placing the stylus over the tracking cross which is located at the top right hand corner of the brace on the tablet. The tablet shows the same diagram as the workscope. He then moves the tracking cross to the desired symbol, i.e., a quarter note, and this note becomes the movable symbol or tracking cross. He then moves the note to the desired position on the staff and drops it by means of a spring loaded switch on the stylus. He continues to drop this symbol until it is no longer needed on this particular brace of music. The composer then chooses another symbol and follows the same process until the music is complete. This process is called "picking."[3]

Once the frame is completed it may be moved to another scope for reference by selecting the command "display." A particular display scope is called upon by selecting the command "Name" and one of the numbers 1 through 9.

By selecting the "clear" command the composer may erase a display and still have it retained in the computer memory. The computer will completely discard a brace when the command "delete" is selected. If the composer wants to hear the music written, he selects the command "play." The named music will then be played through two audio amplifiers attached to the bits of the I/O register.

The "punch" command causes the music to be punched on a paper tape. Cantor did not specify the type of language used. This tape can be re-entered at a later time by calling upon the "read" command. Any symbol or command may be modified at any time by selecting the "erase" command.

The storage capacity of any one brace is 96 symbols. The program has nine braces and therefore a total capacity of 864 symbols. Cantor feels that this is sufficient, stating that Bach's first two-part Invention usually uses 500 symbols.

There are a number of limitations to this system. The playback equipment can only generate a square wave with a timbre something like an oboe. Only one tempo is available. Cantor states that Barker's system allows the composer to

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[3] Ibid., p. 104.

specify the rate of a quarter note in a minute.[4] Cantor also lists the following limitations:[5]

1. Beams are not available.
2. Only upward stems are used.
3. Accidentals must be repeated before each note. [with regards to chromatics as well as key signature.]
4. Only pitches from D-flat below the Bass Clef to B-sharp above the Treble Clef are available.
5. Only one ledger line is permitted between staffs. [This actually limits the Bass Clef range: D-flat to D-sharp, and the Treble Clef from B-flat to B-sharp.]

Cantor suggests that display scopes offer a promising future as a means of input for musical notation.

> One can input music with a display editor faster than one can write it in ink, symbols need only be picked and not formed, material can be erased easily, playback would virtually eliminate copying errors. We ruefully acknowledge that the equipment a display editor uses is at present very expensive. Moreover, a scope, unlike a key-punch for cards or tape, requires the attention of a computer.[6]

He goes on to discuss some of the future possibilities. He imagines an editor of only one scope. This would take the place of the present four. There is also the possibility of treating the display as a continuous strip, with only a few frames showing at one time. He foresees the possibility of displaying five different menus. This would increase the number of available symbols. His proposed program would also have a "define" command. This command, when selected, would allow the composer to describe new unsystematic symbols which are used in twentieth century music.

The limitation of such a program is in the amount of information with which the computer must deal. The program grows, in complexity of description and use, in direct proportion to the number of separate symbols with which it

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[4] *Ibid.*, p. 106.

[5] *Ibid.*

[6] *Ibid.*, p. 108.

must deal. "We will not know how wide a range of music notation can or should be encompassed by a music editor until we try to write and use one."[7]

Graphic-1

Mathews and Rosler proposed another advance in technology in recent years. They have described a procedure for drawing scores as graphical functions of time to replace the system of note cards used for input.[8] The system uses a graphic-input computer, Graphic-1. The heart of the system is an IBM 7094 computer using MUSIC IV programs much the same way as previously described.

> In the past, it has been necessary to specify the note cards in detail. The graphical language to be described allows the note cards to be generated by a computer program, from simpler data specified in terms of functions which vary with time in a piecewise linear manner, and combinations of these functions.[9]

The composer draws his music on the Graphic-1 console. The results, binary data plus conventional key-punched score cards if needed, are fed into the IBM 7094. This converts the images to MUSIC IV. The digital tape output is then transmitted to a PB 250 computer which converts the amplitude samples into voltage. The voltage is then filtered, recorded on magnetic tape, and transmitted to the composer using a tape recorder and loudspeaker.

The Graphic-1 console consists of a light pen for graphical input, a typewriter keyboard for "alphanumeric" input, a card reader for binary input, and a cathode-ray tube for graphical output. Typewriter output is also possible but used only for debugging and error messages. The CRT serves three functions:

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[7] Ibid., p. 109.

[8] Max V. Mathews and L. Rosler, "Graphical Language for the Scores of Computer-Generated Sounds," Perspectives of New Music (Spring-Summer, 1968), p. 84.

[9] Ibid., p. 86.

1. Display area for the contents of the Ampex RVQ buffer memory.
2. Drawing surface for the light pen.
3. Control surface on which various control segments may be displayed.

The control segments or "light buttons" (Cantor described them as "commands") cause introduction of specific subroutines. The light buttons are tailored to fit the problem to be solved; thus, a problem-oriented language. This is the only computer-control language that the composer must learn under this system. The program itself instructs the composer in its own use by displaying various messages. These messages ask for specific data as required by the various subroutines.

The special computer language used on the Graphic-1 is GRIN, which stands for GRaphical INput. The GRIN program divides the display surface into two areas: one for light buttons and messages, and one on which the music functions (amplitude, frequency, duration, and glissando) are drawn. The left to right function of the graph is duration. This may be either in beats or an arbitrary unit proportional to time. The ordinate, or top to bottom, of the graph provides standard scale for pitch or dynamics. If a non-standard scale is to be used an additional typed statement is needed. The light buttons on the upper portion of the graph (not shown) function in much the same way as the "commands" did in Cantor's system and thus will not be described.

Figures 13 and 14 show the first four measures of the march "The British Grenadiers" in conventional notation and when completed on the graph.[10] Each one of the abscissa units equals one eighth note. An example of the normal frequency range is shown on the left-hand side. C4 is middle C, C5 is an octave above and C3 an octave below and so on. An exception to this scale of the graph has been made for this problem and it is shown on the right-hand

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[10] Ibid., p. 103.

Fig. 13

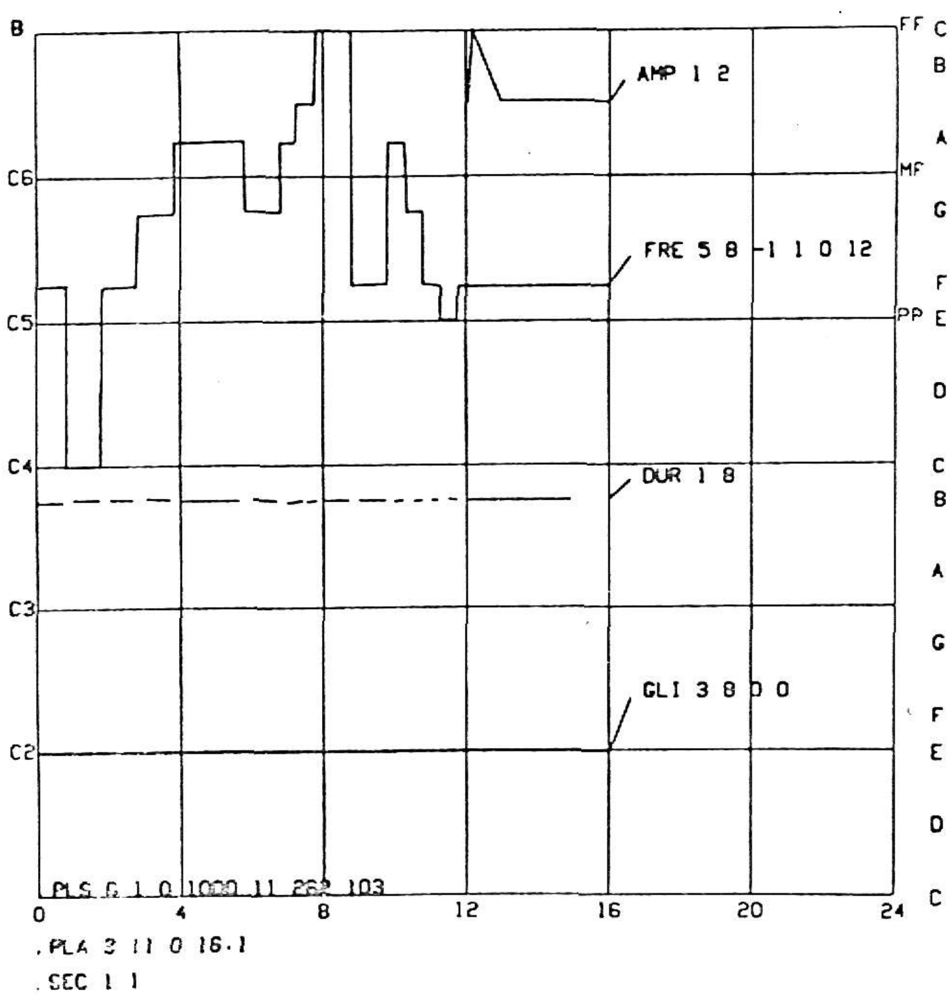

Fig. 14

side. The graph has been modified to show only an octave above and below middle C. This listing, however, is only for the composer's benefit and the program ignores them. The system requires four functions: amplitude, frequency, duration, and glissando (which may or may not be used).

In Figure 14 the upper function describes amplitude and is labeled AMP. The standard scale for amplitude is indicated on the upper right-hand side of the graph, going from PP to FF. The description of this particular function places an accent on the first half beat of each measure and plays the rest of the measure at a uniform rate. The number "1" following the AMP is a count indicating that one additional number follows. The "2" indicates that the function will last two beats.

The function labeled FRE is frequency. The number "5" tells the number of entries to follow. The "8" states that the function will last eight beats. Metronome markings are entered earlier via MUSIC IV. The "-1 1" gives the limits of the music. Corresponding to C below middle C is "-1" while the "1" corresponds to the C one octave above middle C. The number "12" is an arbitrary number that is used to name the complete function. This is necessary for future reference and recall.

The duration function follows labeled DUR. This again states that the duration of the function is eight beats. The duration of each individual note is shown by the dashed line immediately below the line marked C4. This function may also be incorporated into the frequency function by the use of dashed lines instead of the continuous lines as shown in this example.

This particular piece does not make use of the glissando function. Therefore GLI 3 8 00 states that for the eight beat duration the range of glissando is 0 to 0, actually none at all.

Three typed statements appear at the bottom of the graph, and are introduced by the keyboard attached to the console. The PLS statement requests a subroutine to adjust the frequency of the notes so that they coincide exactly with the even tempered F-major scale. This subroutine is requested so that the computer will eliminate any minor errors in drawing the frequency function. The PLA statement requests that the computer play this total score on instrument "11," from beat 0 to beat 16.1. Instrument "11" is a MUSIC IV description of a particular timbre. This has been predescribed to the computer using MUSIC IV and is stored in the computer memory. The reader will notice that the duration of this PLA statement is 16 beats. This is twice the duration of the FRE and DUR functions. This demand will therefore produce two repetitions of the four measures stated above. The third statement, SEC, terminates this section of the music.

Many additional features were added to the graphical language. One feature is an algebra for combining functions. With the use of this algebra one can gradually convert one rhythmic or melodic pattern into another. The system may also average two melodic or rhythmic lines. An example of this conversion process is described by Mathews and Rosler.[11] In the example, the march "The British Grenadiers" is gradually converted into the melody "When Johnny Comes Marching Home" and back. The authors state that this is ". . . a nauseating musical experience but one not without interest, particularly in the rhythmic conversions."[12] The use of this algebraic function seems to open many possibilities for computer improvisation.

The authors state that the experiments they have described have three distinct implications.[13]

> 1. Graphical input via a cathode-ray tube, light pen, and associated programs is an effective way for a man to communicate with a computer.

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[11] Ibid., p. 112.

[12] Ibid.

[13] Ibid.

2. Graphic scores are excellent for expressing many sound sequences.
3. Algorithmic composition is possible.

CRT input certainly seems easier than using punch cards or tape input. Scores serve two main functions. They help the composer to organize and remember his ideas and help the listener to follow and learn the composition.

Through the use of algorithms, details in generating individual notes may be simplified. The composer has greater control of his composition. The authors believe that ". . . algorithmic composition is the beginning of a revolution in the musical use of computers."[14] It must be noted that this paper was originally presented in 1966.

Mathews and Rosler, in this presentation, seem to place the importance on the graphical language itself. Hubert S. Howe, Jr., in reviewing the article, places the importance on the interaction of the Graphic-1 and the composer.

> It is possible for a composer to describe what he wants to the computer and then hear the results played back immediately. This procedure is unquestionably the most important technological improvement discussed in the entire book, [Music by Computers] and if it could be implemented at any general installation it would lead to entirely new methods and concepts.[15]

Sound Description

One of the major problems confronting the computer composer is the description of sound. It has been stated that any sound which can be mathematically described can be produced by a computer. Until recent years conventional musical instruments have been the most difficult to describe. Nuances in the timbre quality of the instruments have not been fully understood. One attempt

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[14] Ibid., p. 113.

[15] Hubert S. Howe, Jr., review of Music by Computers, ed. by H. Von Forester and James W. Beauchamp, in Perspectives of New Music (Spring-Summer, 1970), p. 154.

to describe these phenomena has been made by James W. Beauchamp at the University of Illinois.

Beauchamp created a system which describes the sound output of a musical instrument over its complete dynamic and pitch range. The system uses an Analog-to-Digital converter which is the reverse of a Digital-to-Analog converter. This machine takes sound, which is recorded through microphones as voltage, and converts it into digital form.

Three instruments were used for the experiment, a flute, oboe, and cornet. Performers were taken into an acoustic chamber and asked to play several tones. These tones were carefully recorded and classified and then converted to digital data. This data was then subjected to harmonic spectrum analysis by a computer. The result was information regarding the growth and decay of each harmonic partial of the tone over its duration. This information was plotted visually on a graph. Through a method of approximating the complicated curves of the graph by computer, the tone was then digitally synthesized. As a control procedure the digital information was then converted back into sound by a D/A converter. This sound was compared to the original sound and the accuracy of the analysis was confirmed.

The entire project used five different facilities at the University of Illinois and four different computers. Hubert Howe states: "This is unquestionably one of the most important undertakings of this kind in recent years, one which required a technical expertice and special facilities available only in a few places in the world."[16]

How goes on to point out what to him are some of the disappointing aspects of the study. He lists the following criticisms:[17]

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[16] Ibid., p. 156.

[17] Ibid., p. 157.

1. Not enough careful auditory analysis of the tones was made before they were submitted to computer analysis.
2. Tones were played under unusual circumstances.
3. Because of storage capacity of one of the computers used, maximum duration of .997 seconds, only short tones were used.
4. Method of synthesis used, copying the results of the analysis, even though it was only used for control.

Howe goes on to state, however, that the study provides a model for future research. "What we really learn from Beauchamps' article is that this kind of study is tremendously complicated and requires technical knowledge and facilities of great depth."[18]

Jean Claude Risset has compiled "An Introductory Catalogue of Computer Synthesized Sound." He has determined the mathematical description for good imitations of familiar sounds as well as unfamiliar ones. James W. Beauchamp, in reviewing this technical report in Perspectives of New Music,[19] states that Risset's work forms an excellent basis for composers who would like to explore the use of a similar or related sound. Since Risset uses MUSIC V, a familiarity with Mathews' The Technology of Computer Music[20] is needed to interpret the work.

Risset has divided the sounds into three categories: wind-like, percussion, and spectrum and pitch glissandi. Sounds relative to flute, clarinet, brass-like, double reed, piano, drum, bell, and gong-like are described. These are only relative representations and do not incorporate Beauchamp's own work in the descriptions. Risset has also improved MUSIC V by adding several

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[18] Ibid.

[19] James W. Beauchamp, review of "An Introductory Catalogue of Computer Synthesized Sound," by Jean Claude Risset, in Perspectives of New Music (Spring-Summer, Fall-Winter, 1971), p. 348.

[20] Max V. Mathews, The Technology of Computer Music (Cambridge: Riverside Press, Inc., 1969).

generation routines and other modifications.

Beauchamp states that as a result of this study one can look forward to a promising future for computer music.

> As definitions for flexible but easy-to-use 'instruments' are accumulated (and computer systems get faster and cheaper), composers can concentrate on the higher levels of composition.[21]

[21] James W. Beauchamp, review of "Introductory Catalogue," p. 350.

CHAPTER VI

THE FUTURE OF COMPUTER MUSIC

As the present stage of the computer's contribution to music is embryonic, it would be impossible to assume a definite future. One complicating factor in trying to predict a future is the unsystematic way in which musical uses of the computer have evolved. One is struck by the multiplicity of ideas and procedures and by the diversity of techniques, terminology, and goals that are present today. There are many different types of programs for composition, sound synthesis, control voltage, and analytical processes. However, there are certain desirable characteristics that a computer system must meet in order to serve as an analyst of musical tones, a composer, and/or a musical instrument of the future. Attainment of these desirable characteristics will certainly affect and determine the future of computer music.

One of the most desirable computer characteristics is that of operation in real-time. Continuous real-time operation will increase the value of computer composition by giving the composer the needed freedom to modify his results while they are still fresh in his mind. M. David Freedman, of Bendix Research Laboratories, lists several requirements that an on-line synthesis system which operates in real-time must meet.[1]

1. The computer must be accessible to the composer when he needs it.
2. The music generating equipment must be compatible with the high data rates necessary for pleasant sounding music.

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[1] M. David Freedman, "On-line Generation of Sound," Music by Computers, ed. by H. Von Forester and James W. Beauchamp (New York: John Wiley and Sons, 1969), p. 14.

3. The music must be produced continuously in-time.

Freedman states that the simplest way to assure that a computer will be accessible is to have a free-standing computer for use as a music console. He states, however, that this would not be economically feasible. As input/output devices become more rapid, the feasibility of this type of system will increase. He sets forth another solution to the first requirement as using a smaller computer for input/output functions and use a larger computer on a time-sharing system for storage and computing functions. This solution is being carried out, to some extent, at the University of Illinois, utilizing the CSL system previously discussed.

Increased speed and simplification of the input/output devices are also major considerations for the future. As was previously stated in Chapter II, a large amount of time was spent in preparing the program and transcribing the output notation of early computer compositions. Technology has advanced to such a level that the latter requires a minimum of the composer's time. It is hoped that in the future this time will be further reduced. The problem of initial communication with the computer still exists.

> The usual method of communicating with a computer suffers from long delays between 'action' and 'reaction.' A deck of Hollerith cards is submitted and a batch processed along with other jobs. These delays range from overnight to several days and can be quite intolerable.[2]

Although technologists are trying to solve this problem, possibilities for the future are not exhausted. Mathews and Rosler believe, for instance, that their graphic representations of scores are better than conventional scores for computer music. "We expect a great deal of music of the future will be

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[2] *Ibid.*, p. 16.

scored graphically."[3] Greater use and development of the Music Editor is a possibility for the future. This system seems to be the most closely related system of notation to that which most composers are accustomed to using.

Important technological innovations have resulted from, and will continue to be established from, the area of academic research. Although the area of musicology has not been discussed in this paper, important innovations which are the result of analytical research has improved composition and generation hardware and software. One development, the automatic printing of music from a representation, appears to be in the near future. Stefan Bauer-Mengelberg has developed the Ford-Columbia representation already in use by a number of researchers. This representation is ". . . a graphic-oriented representation for use in a photo composition meachine known as the Photon."[4] The future possibility of this system being used for transcription of computer output (described in Chapter II, p. 8) for conventional instruments, would increase immediacy of realization.

Another possibility for the musicologist is that of an optical scanner.[5] It is envisioned that the machine would be able to read conventional music and convert its reading to representation. This system, adapted to computer generation, could possibly reduce the amount of time required for input processes. The multiplicity of programs and languages coupled with greater communication between experimenting individuals will eventually reduce the problem of communication with computers for the future.

The use of computers provides a promising future for the musicologist in

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[3] Max V. Mathews and L. Rosler, "Graphical Language for the Scores of Computer-Generated Sounds," Perspectives of New Music (Spring-Summer, 1968), p. 114.

[4] Harry B. Lincoln, ed., The Computer and Music (Ithaca and London: Cornell University Press, Inc., 1969), p. xiii.

[5] Ibid.

the amount of study which may be undertaken. "The computer allows the scholar to accomplish in a short time what would have otherwise taken him up to a whole lifetime of drudgery to accomplish."[6] Edmund A. Bowles in "Musicke's Handmaiden: or Technology in the Service of the Arts" states that: "Another manifestation of this change of pace has been greater precision of thinking."[7] The necessity of providing exact information to the computer compels the user to force the issues at hand more explicitly.

A large factor in the success or failure of computer music in the future is the evaluation of the music by the listener. From the listener's standpoint, one of the problems in computer music is perfection. The musician is always striving to play precisely in tune, rhythmically correct, and to accurately represent the composer's wishes. The computer does this flawlessly by generating sound regularly, consistently, and very predictably. As a matter of tradition, listeners are accustomed to hearing music which is not perfect in every parameter. This imperfection creates a certain amount of interest within the music.

Gerald Strang, of California State University at Long Beach, poses some suggestions for the solution of this problem.[8] One suggestion is the introduction of timbre variation to particular instruments as they change registers. This solution is actually one of the purposes of Beauchamp's study previously

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[6] Edmund A. Bowles, "Musicke's Handmaiden: or Technology in the Service of the Arts," The Computer and Music, ed. by Harry B. Lincoln (Ithaca and London: Cornell University Press, 1970), p. 19.

[7] Ibid., p. 20.

[8] Gerald Strang, "The Problem of Imperfection in Computer Music," Music by Computers, ed. by H. Von Forester and James W. Beauchamp (New York: John Wiley and Sons, 1969), p. 133.

described.[9] Strang states, however, that this is not practical because of the computer time required to calculate one second of sound with present systems. "Three minutes of computer time were required to calculate one second of sound--a 180:1 time scale."[10] It should be noted that the system of synthesis used was not described by Strang and therefore could not be compared to Beauchamp's. Other suggestions by Strang are the introduction of small amounts of irregular vibrato and the introduction of some out-of-tuneness. He also suggests greater use of different meters within a composition. Strang leaves the evaluation of these factors to the listener.

> Neither the nonperformers nor the professionals appear to approve of the maximum level of computer 'perfection.' Listeners object to the 'electronic organ sound,' or the 'machine sound' and ask for more warmth and spontaneity. . . . Perhaps they prefer 'imperfection' primarily because they have never heard anything else.[11]

Arthur Layzer, in an article in the American Society of University Composers Proceeding, 1971, states that the listener of computer music should accept it as a new medium and not try to convert it to imitate existing media. He feels that to add imperfection to computer music, the computer composer would be creating mere imitation of existing sounds. He states: ". . . if one allows the personality of the computer to show through one has achieved a higher level of perspective than mere imitation. . . ."[12] Layzer points out

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[9] Chapter V, p. 36.

[10] Strang, "Imperfection," p. 136.

[11] Ibid., p. 138.

[12] Arthur Layzer, "Some Idiosyncratic Aspects of Computer Synthesized Sound," American Society of University Composers Proceeding, 1971 (Spring, 1973), p. 30.

that one of the interesting factors in computer music for the listener is comparing it to conventional instrumental music. Computer music can be an enjoyable and, at times, a humorous experience.

Computer generation of music offers a promising future for the composer since the computer, as an instrument, escapes some of the limitations of conventional orchestral instruments. Performance capabilities of the musicians and instruments do not restrict the computer composer. The computer allows the composer to be a composer and not be tied down to work within a restricted medium. Hiller states in reference to twentieth century music: "It would seem that the threshold level of our ability to perceive complex and tonal combinations exceeds present performance capacities."[13] In a computer based system the composer has nearly perfect control over duration of sounds and the spaces separating them. This makes it possible to create and realize complex rhythmic patterns which would otherwise be impossible for the musician to play. Possibility also exists for exploration of different intervalic divisions within the octave and therefore new scales and temperaments may be produced. Unlike musicians, the computer does not interpret and will play in any describable scale with equal impartiality.

Computers have the capability of performing the composer's composition without rehearsal. This should be considered when discussing the seemingly large cost of computer music. The computer composer need not hire musicians for rehearsal or performance, rent a studio, or pay recording technicians. His only cost is that of the computer facilities. The future holds great promise for reduction of cost for computer time, hardware, and related services.

Miniaturization in twentieth century technology is a major concern.

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[13] Lejaren A. Hiller, Jr., and Leonard M. Isaacson, Experimental Music (New York: McGraw-Hill Book Co., Inc., 1959), p. 176.

Governmental experimentation in the space program has resulted in a computer the size of a shoe box for use in space capsules. Decreasing the production cost of equipment is also a concern of the twentieth century technologist. Computers have followed the progress of other twentieth century electronic equipment such as calculators, televisions, tape recorders, etc., in decreasing the size and cost. Since initial cost is being reduced, more institutions will be able to create computer facilities which will make the computer more accessible to the musician.

Many of the problems pertaining to the relationship of music and technology have already been solved. However, composers (for the most part) have not had the opportunity to work with existing systems and the related necessary team of physicist, programmer, engineer, and computer. The limited number of centers in which music may be synthesized and analogued as well as the high cost of computer time make current programs somewhat impractical, and in many cases only experimental. However, the promise of continuing largesse for research in the fields of electronics and physics as well as the ideological hope of the composer working in an expanded world of sound assures continuing work and advancement in the field.

GLOSSARY

algorithmic composition: a process which uses algorithms to determine the greatest common denominator between two notes.

alphanumeric: a contraction for alphabetic and numeric.

binary number system: a number system based on the numbers in Base 2.

buffer: temporary storage section for data between an input or output device and the computer.

console: control panel used by the computer operator.

CRT: cathode-ray tube.

CSL: Consolidated Science Laboratory.

digital-to-analog converter: a device for converting digital data to voltage (D/A).

hardware: machines.

instrument: a combination of unit generators which produce a certain characteristic sound.

interface: a common connection between computer systems.

interrupt: point at which a computer program may be interrupted to perform a different operation and then return to the original operation.

on-line: under the control and connected to the central processing unit.

orchestra: see instrument.

program: the set of instructions to solve a problem.

real-time: the processing of information as received and in time for the results to be available for influencing the process being controlled.

sampling: process of recording a wave form at equally spaced intervals.

score: computer program for generation of specific sound.

software: programs and languages.

subroutine: a set of computer instructions to carry out a predefined computation.

time-sharing: carrying out two or more functions during the same time period by allocating small divisions of the total time to each function in turn.

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AN INTRODUCTION TO THE COMPOSITION AND GENERATION OF COMPUTER MUSIC

by

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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF MUSIC

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The purpose of this report is to give a general introduction to computers and their usage as a medium for composition and generation of sound. Chapters include an Introduction to Computers, Computer Composition, Computer Generation of Sound, Methods of Computer Generation of Sound, Technological Advancements and Experiments, and the Future of Computer Music. The report is not intended to be an inclusive study of all of the equipment, programs, and languages that have been or are being developed at this time. Developments in hardware (machines) and software (programs and languages) over the past decade have continued at a rapid pace. These developments are numerous and are happening simultaneously throughout the world; many of them are the results of experimentation completely independent of computer music. Researchers are hampered in identifying and explaining the numerous and rapid developments because of communication problems between experimenting individuals. Many accounts of systems are recorded in unavailable, or difficult to obtain, laboratory and technical reports.

The experiments and developments discussed in this paper were chosen because of their direct bearing on the computer composer. Most of these simplify the composer's task and enable him to devote more concentration to the composition of music. With a few exceptions, this report deals with studies and developments prior to 1970 in the United States. The author makes no attempt to evaluate which program, language, or equipment is superior. Each has its own purpose, and each individual must choose the hardware and software which best suit his need and the capabilities of his equipment.