The Use of Computer Programmes in Creating Music

1. BACKGROUND

For the purposes of musical production computer programmes are used in an attempt to fix in advance, in accordance with rules, the course of a musical form or a musical sound. In musical analysis, they can reveal the rules obeyed by the composer, or at least indicate his stylistic characteristics.

The use of computers is based on the assumption that musical form is not merely the result of inspiration, guided perhaps by experience, but that it obeys communicable rules which theoretically can be used by anyone who takes the trouble to learn them. Musical sounds may be described as a function of amplitude over time.

The use of computers is the logical outcome of a historical development. It by no means heralds a new musical epoch; it simply offers a fast, reliable and versatile means of solving problems that already demanded solution. The person who writes the computer programme must bear the development of musical language up to the present in mind, and try to advance a stage further.

This study attempts to make a brief historical survey and indicate the notation problems that arise from the composer's work with the computer. It concludes with two practical examples (a composing programme and the automation of an electronic music studio by means of a computer).

Rules of musical composition

More than any other art form, music tends to have rules for its composition. There are rules for rhyming and metre, perspective and colour mixtures, drama and so on. But poetry, painting, acting and sculpture have natural objects as their model, or their geometric abstractions. Literature uses a language which is also used to communicate in everyday life. But music does not portray nature; the world of musical sounds and expression is absolutely artificial – there is no corrective in the form of a natural model. Whereas the model can be recognized in illustrative art, music, if it does not produce psychological associations or imitate the gesture of spoken language, must establish its "non-natural" sound formations in such a way that they can be repeated, recognized, altered and further developed.

We encounter examples of musical rules in counterpoint and harmony. Counterpoint proceeds from the one-part melody and regulates the sequence of pitches in an approximation of the natural flow of speech. As soon as several melodies occur together to form polyphony, a harmonic problem arises: although each individual part has to obey the melodic rules, each chord must also be checked. But even where the harmonic rules are in contradiction to the melodic and are ignored in favour of the latter, the struggle of the part-writing communicates itself to the chords, and especially to the sequence of chords.

In harmonic writing, which obeys the rules of tonal harmony, the chords, which originated in the superposition of several parts, are treated as having an independent existence. There are fixed rules for the construction of the chord from single notes and for joining chords together; but the moment chords have to be distributed among several parts for the purposes of performance, a problem arises – this time the other way around. However, in this case, the strength of the chordal progression is communicated to the individual parts if the latter's progress contravenes the melodic rules.

Counterpoint and harmony, of course, tell us little about the construction of musical form, which has its own set of rules. These, however, are less binding than those of melody or harmony.

Serial music

Arnold Schoenberg's twelve-note technique resulted from the consequences of a further development of polyphonic and chordal music which was threatening to break up tonality; at the same time it is an attempt to resolve the contradiction between simultaneity and succession. It puts the twelve semitones of the octave into a prescribed order *(series* or *row)* in which no note may be repeated. All melodic and harmonic progressions must be derived from this series and its inversions and transpositions. However, the theory says nothing about the manner in which the notes of the series may be treated rhythmically or combined to form chords; but it does allow the composer sufficient freedom to resort to the criteria of tonal forms or to invent other regulative devices.

It was not until after 1945, however, that a number of young composers attempted to apply serial control to other musical parameters. Not only pitches, but also dynamics, durations and timbres were arranged in series, so that several kinds of series intersected at each single note. The serial mechanism allowed all details to be fixed programmatically – the sequence of individual sounds, and formal criteria pertaining to changing density of context or the predominance of individual parameter values *(group composition).* These serial composers had no desire to subordinate their artistic responsibility to a system of rules, but saw a real chance of preserving the spontaneity that derives from the invention of combination patterns; the rules cause all events to be predictable, but there can still be surprising situations for the listener. With developments, climaxes or simply an agreeable-sounding texture, such situations belong to the criteria of earlier music which even serial composers did not wish to renounce. Eventually it became apparent that random criteria could also be introduced into serial technique, thereby not only causing an increase in unpredictability, but also providing a composition-technical basis for the desire for scattering techniques, the definition of fields, freedom from "pointillist" determinations for each individual tone.

Performance technique

Performance is another programmatic aspect of music. Any score, for large orchestra, chamber group, or soloist, can be regarded as a linear programme which gives instructions to the players for the duration of the performance, about the exact order or a series of actions. If the interpreters have freedom extending to group improvisation for which only general indications can be given, the programme must have branches. As regards performance technique, the composer is also accustomed to making use of a kind of programming.

Mechanical music

The necessity of making each individual sound audible by mechanical means and of fixing the player's actions accordingly by means of graphic symbols which are not always unambiguous led to all kinds of experiments in mechanizing both sound production and communication. Mechanized sound production has been especially successful in the case of keyboard instruments; the ancestors of mechanical communication are musical boxes and mechanical pianos.

Electronic music can also be considered in this light. The composer originally had to set every single sound at the oscillator and cut it to the right length of tape with a pair of scissors. The development of punch-tape control, voltage control and, finally, the introduction of the computer have made the programmatic aspect of this type of sound production increasingly clear. The relatively slow speed of tape-readers means that oscillators or filters have to be set before being switched. One speaks of "sequences", because in this way only the order of given signals can be determined. For voltage control, however, direct voltage signals are either produced by suitable function generators or obtained by the demodulation of audio signals. These signals can then be used to control voltage-dependent amplifiers, oscillators or filters.

Punch combinations and direct voltage signals represent programmes which unambiguously fix the course of musical *sounds* in several parameters. These methods developed from the need to simplify the production of sounds in the electronic studio or at least to subject them to strict control. But it can be seen that the need to control musical *form* can be satisfied too if what the composer understands by form is the end-product of all physical parameters.

2. COMPUTER PROGRAMMES

The use of computers for purposes of musical production is a logical result of historical developments. Every rule of composition that can be formulated can also be programmed and carried out by a computer. According to the tasks the computer is asked to perform, there can be programmes for

- composition (score),
- sound production (instrumental or electronic sounds),
- controlling voltage-dependent studio apparatus,
- the analysis of scores or sounds.

Naturally, one does not programme known rules of composition but also tries to find out whether events not yet expressed in the form of rules are feasible. The computer thus has a stimulating effect on research in composition theory.

A few programmes that have emerged from the experimental stage have been published, and several compositions produced with the computer's help, e.g. those of Xenakis, Hiller or Brün, to name but a few, or the well-known Music V programme. The programmes usually link with accepted terms (rules for harmony, counterpoint, serial or aleatory compositional technique). Unless orientated towards the types of sound that occur in electronic music, sound production is generally preceded by an analysis of the instrumental sounds. If punch-tapes or computers are used in studios in the process of automation. their employment depends on the control facilities of each such studio. Musical analysis presents great difficulties, as the problems involved are still a matter of debate; once the musicologist knows what aspect he wishes to investigate, the main problem is already solved. It is no less difficult for the composer to provide indications for the analysis of his own works. Since composing programmes involves countless random decisions, it is desirable to make the progress of the composition dependent on decisions which have already been made. The Institute of Sonology of Utrecht intends to work on this problem during the next few years. Attempts at computer-controlled printed notation have also been made and plotters have produced musical graphics. Apart from the fixing of composition rules, the analysis of given texts, or analysis during composition for the purpose of modifying further decisions, the question also arises as to whether musical theory will not be increasingly compelled to regard the computer as its most perfect tool. The complexity of qualitative criteria in particular practically excludes the use of the computer; it would have to be quantified, and thus brought within the purview of musical rationality. But even here, the previous limitations will surely diminish. It is not by chance that the development of computer programmes has up to now concentrated on familiar quantities (instrumental sounds, electronic sound-types, measure, parts, orchestra); but I feel that the time has come to bring the most advanced position in music within the computer's scope. It is not, however, the purpose of this study to go into this question. We shall now consider to what extent the computer affects notation problems in music.

3. NOTATION PROBLEMS

The purpose of notation in music is to provide an unambiguous means of communication between composer and interpreter. Numerous attempts to improve, or even replace, traditional notation, indicate that the communication is by no means wholly satisfactory. Electronic music has not yet found any generally accepted notation. Individual composers have succeeded in writing unequivocal instructions for studio performance, but these scores usually do not allow the listener to follow it, i.e. they do not convey a visual impression of the acoustic events.

Still, difficulties in communication between composer and performer already existed before computers, and do not derive intrinsically from the use of computers. Standard programme languages are used in writing the computer instructions, so that there are no notation problems here. Standard typewriter symbols are used for data output. Although they must be transcribed by the composer into musical notation symbols, this does not affect the notation problems referred to above. Seen in this light, then, no notation problems are involved in computer use. Furthermore, the computer output is intended for the composer who will have to transcribe it and not for the performer or audience. Sounds produced by the computer are fixed, not graphically, but straight on to audio tape. In musical analysis, the output is intended for the person doing the analysing, who communicates in this way with himself and not with the outside world: the analysis evaluation in then published in the usual written form. Lastly, control voltages produced by the computer are not written down but fed straight to studio equipment by means of electric connexions.

If, however, we ask ourselves how the composer makes contact with the computer, communication problems – and hence notation problems – arise (we shall disregard composers who have their own private computer). First, the composer requires a programme, which means he gets in touch with a programmer. If he is lucky, the programmer knows musical terminology; otherwise there are serious difficulties in communication. Should the composer want to make himself independent of the programmer by learning about the computer's possibilities and then trying to work with them, he will find he can barely formulate his own ideas. He could of course learn a programme language in order to communicate better with the programmer, or he might even write his own programmes. He could master the language in a couple of weeks, but it would take months, if not years (provided he had a computer available with which he could practise regularly) to learn to use it in handling complex musical problems.

It is indeed difficult to say whether the composer should do his own programming or rely on telling a professional programmer what he wants. No driver has to build his own car, no listener his own radio. Even composers of electronic music have ready-equipped studios at their disposal in which they can put their ideas into practice without electro-acoustic knowledge. Should the computer centres (or electronic studios with computers) not make musical programmes available which composers with no previous knowledge of computers might use ? The problem of notation is then this: *what must a musical programme do for the composition or sound production?* and *in what form should the composer write his requirements so that they can be used directly as input for an existing programme without previous translation into a programme language?*

If then we regard the computer as an instrument with a panel as easy to understand and utilize as that of a radio or an electric filter, our survey of notation problems in computer music would include the following points:

- System of data input for composing programmes,
- System of data input for sound production,
- Data output in the form of tables for composing programmes which can be easily transcribed into any required notation system,
- Graphic data output for composing programmes with the aid of plotters or similar devices,
- Use of plotters, music-typewriters or similar devices for the production of scores and parts.

This list could be extended by including notation problems resulting from the analysis of scores or sounds, and one other question: how may a computer which produces "real-time" music in the concert-hall be influenced by the composer (or audience) during performance ?

However, many of these problems, and especially the last, are still in the realm of speculation. It may be true that the computer can do anything; it is also true that, in practice, there is very little that can yet be done with the computer in music. Composers can have players, orchestras, conductors, even studios for electronic music completely equipped and serviced, but a composer who wants to compose with computers has practically no facilities for doing so. It is not much help to him to be told that he can write his own programmes, or that he may occasionally have the help of a programmer. The computer must be placed within the composer's reach, as the facilities of the electronic studio have already been for quite a long time. Apart from a few exceptions, as far as I can see, the computer just represents a problem of notation for the composer i.e. a problem of communication. It is not enough to count the notes in the score, to imitate traditional musical instruments, to programme electronic studios. These are all highly interesting and can keep the specialists busy for years, but they are not much use to the composer. I believe that very considerable efforts must still be made to provide the composer, and even the music student, with a computer as a tool for musical creativity and as a medium of empirical experience, with as little fuss as he can be provided with a piano or an electronic music studio.

4. EXPERIMENTS AT UTRECHT

To end, the following is a report on an experience in the Institute of Sonology at Utrecht University. The Institute has a large studio for electronic music which in recent years has developed its own system of voltage control. Computers are to be employed in musical composition, voltage control, sound production, musical graphics, musical analysis, perception research.

So far, research was intended partly as a preparation for sound production and has been concentrated on musical composition. A Hewlett-Packard computer to be purchased in 1970 will be used first for voltage control, later (in collaboration with the university's computer centre) for sound production, and for purposes of notation and musical graphics. Musical analysis is regarded as a part of the composition project and will be handled in conjunction with it during the next few years. Perception research (on non-stationary sounds) will utilize the results of sound production. A discussion on the notation problems of musical composition follows, and on preparations for studio automation.

Musical composition

The first point to be settled in writing composing programmes is: *What, in music, can be programmed? i.e. apart from the decisions which the composer makes once, are there also recurring decisions which can be established as compositional rules? Do such rules apply only for one piece, or for several different kinds of pieces?*

The author's first attempt at an answer resulted in a composing programme called *Project 1* (which will be described in the second issue of Electronic Music Reports, an occasional publication of the Institute of Sonology). The programme contains rules and a number of individual data so that it was possible to produce only a number – although quite a large number – of variants of the given set of rules. It cannot have much interest for other composers as they can exert hardly any influence on the rules and the individual data. So far the programme has been used to produce three instrumental compositions.

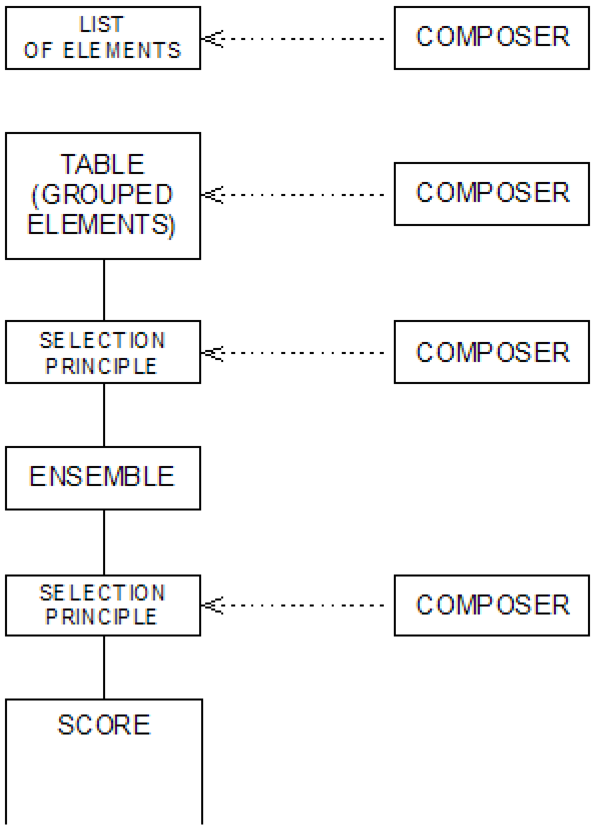
The next development was *Project 2* (a manual will appear as Volume 3 of the Electronic Music Reports). This new, more comprehensive programme involves seven parameters which are named: Instrument, Harmony, Register, Entry Delay, Duration, Rest, Dynamics.

The composer can provide as many data as he wishes for each parameter; furthermore, several sub-programmes select the data according to various principles and assemble them to form the score. The composer determines the compositional rules on the basis of these selection principles and combinations of them, but also by indicating the order in which the parameters are to be computed, for the parameters depend on one another in such a way that, for instance, no tones may be selected which a given instrument cannot play, and vice-versa, according to the order determined by the composer. At all levels of decision, chance is given opportunities to operate to a greater or lesser extent, so that any number of variants can be composed according to the data.

The guiding principle behind *Project 2* was to describe the possibilities of the programmes in the special language of music. For this, terms from serial compositional technique were chosen. A second purpose was to spare the composer superfluous writing – mainly in order to reduce the quota of errors. A third, resulting directly from the first, was to eliminate the need for a previous knowledge of computer technique or mathematics.

The List-Table-Ensemble principle was accordingly developed and applied to five of the seven parameters (Fig. 1). The list registers the elements of the parameter concerned, whether these be numerical or alpha-numeric information. The table allows the elements from the list to be combined into groups. The composer makes a preliminary sorting. For each variant, a different group, for example, can then be called. The group thus called (or combination of groups) is then available in the ensemble. The number and selection of groups for the ensemble depend on one of the selection principles. These selection principles are also brought into play in the last phase, which is the assembly of the score by means of the elements in the ensemble.

Uniform questions were formulated for the parameters affected by the List-Table-Ensemble principle (Fig. 2). For duration, for example, they are



- Which durations? (The composer inserts the required duration list);
- Which table? (The composer puts groups together from the indices of the elements from the list);
- Which group? (The composer determines a selection principle according to which a selection from among the groups of tables is to be made; the number of groups is decided at another point in the programme);
- Which durations? (The composer again determines a selection principle).

The catalogue of questions for the duration parameter contains two additional questions:

- What ratio to the entry delays? (The composer has three alternatives from which to choose);
- Durations within a chord? (The composer may choose between equal or unequal durations of the tones in the chord; whether chords can occur at all is decided elsewhere in the programme).

Fig. 1

Project 2
The List-Table-Ensemble Principle

33 WHICH DURATIONS?	
34 DURATION GROUPS (TABLE)	
35 WHICH GROUPS?	1 ALEA
	2 SERIES
	3 SEQUENCE :
36 WHICH DURATIONS?	1 ALEA
	3 RATIO :
	4 GROUP a: z: type 1 2 3 4
	5 SEQUENCE :
	6 TENDENCY d: a1: a2: z1: z2:
37 RATIO	0 INDEPENDENT
	1 DURATION = ENTRY DELAY
	2 DURATION <= ENTRY DELAY 83
DURATIONS IN CHORD	0 EQUAL
	1 UNEQUAL

Fig. 2
DATA FORM – PARAMETER DURATION

Each question is provided with a call number, as are the selection principles. ALEA selects randomly (that is without a repetition check) among the given elements, SERIES selects randomly with a repetition control so that an element, once selected, is blocked until all elements from the list (or all groups from the table) have been selected once. In the RATIO principle the duration of the repetition check depends on a ratio quantity which must be given for each list-element; the element repetitions are distributed randomly. GROUP produces repetitions of the elements in groups; a and z indicate the minimum and maximum sizes of the groups; the numbers for the type refer to combinations of the ALEA and SERIES principles for the selection of the element and the size of the group. SEQUENCE permits the composer to determine the order of the elements (and groups in the table) himself. Lastly, TENDENCY works with a mask, the edges of which move across the ensemble independently of each other; ALEA selects among the "visible" elements. The terms d, a1, a2, z1 and z2 control the mask's movements, in percentages of the size of the ensemble.

The composer states the call number of each question, the call number of the selection principle (if required) and the elements and parameters of the selection principle. All the data are stored in the computer, so that for further variant-groups only the questions have to be answered to which different answers should be given. Apart from the fact that this system can be extended at any time, it also enables the composer to write with great economy data which ought not to exceed the range of his compositional experience. The selection principles ALEA, SERIES, RATIO, GROUP and TENDENCY and the parameters DYNAMICS, HARMONY (including REGISTER) and time (ENTRY DELAY, DURATION and REST) are also available separately for purposes of studying Project 2.

For the data output, the notation problem is the printing of the notes or a musical graphic. Scores printed or drawn by the computer are not only required for a performance but even earlier, for tests, and for the comparison of several variants. Lengthy experiments with the line printer convinced me that the results could not be read easily. Experiments with music typewriters (Hiller) show more promise, but as far as I know, there are no programme-controlled music-writers on the market. Plotters or screens could be used if a computer centre possesses them and can make them available for such time-consuming work. At present the data output of *Project 2* is limited to printed tables of the composed results, consisting of several parts.

The input data are printed first (Fig. 3), to be followed by preparatory decisions with regard to group formation and the order of the parameters (Fig. 4), and pertaining to the contents of the ensemble and the order of the elements for the score (Fig. 5). The second part contains the complete score (Fig. 6) with columns for instrument, manner of playing, pitch, dynamics and duration (beginning and end of a tone in seconds). The COMMENT column contains any indications that might be needed to show that a particular parameter value cannot be ascertained because of the given rules. In the third part (Fig. 7) the data are printed for each part and combined into metres. The composer is free to combine several metres to form a measure. The following are printed in columns: the current number of the metre, the pitch, beginning and end of the tone with regard to the metrical subdivision, dynamics and manner of playing. For the pitch. the first number indicates the octave and the other two indicate the tone within the octave. The metrical subdivision is represented by two numbers: the first indicates the number of subdivisions (e.g. quintuplet), the second the point in time at which the tone begins or ends. Transcribing this third part into notation has proved to be practical and quick, the second part – except for purposes of checking – being suitable for scores to scale in which the durations are indicated by lines of corresponding lengths. Fig. 8 shows an example of a score (*Übung für Klavier* by the author), from which the previous figures were also taken.

	Call	Name	Count	Elements										
*	25	L-REG	2	207	706									
*	26	TAB-REG	1	1										
	27	SEQ-GR-REG	1	1										
	28	SEQ-REG	1	1										
	29	L-ENTRY	20	.10	.12	.15	.19	.24	.30	.37	.46	.58	.72	.89
				1.11	1.38	1.72	2.14	2.67	3.32	4.13	5.14	6.40		
*	30	TAB-ENTRY	7	8	9	10	11	12	13	14				
	31	SEQ-GR-ENTRY	1	1										
	32	SEQ-ENTRY	1	1										
	33	L-DUR	20	.10	.12	.15	.19	.24	.30	.37	.46	.58	.72	.89
				1.11	1.38	1.72	2.14	2.67	3.32	4.13	5.14	6.40		
	34	TAB-DUR	10	1	2	3	4	5	6	7	8	9	10	
	35	SEQ-GR-DUR	1	1										
	36	SEQ-DUR	1	1										
*	37	DUR-ENTRY	1	1										
	38	MOD-DUR	1	0										
	39	L-REST	1	.01										
	40	TAB-REST	1	1										
	41	SEQ-GR-REST	1	1										
	42	SEQ-REST	1	1										
*	43	MOD-REST	3	1	10	25								
	44	L-DYN	16	PP,P,MP,MF,F,FF										
	45	TAB-DYN	6	1	2	3	4	5	6					
	46	SEQ-GR-DYN	1	1										
*	47	SEQ-DYN	7	3	1	1	1	1	1	1				
	48	MOD-DYN	1	0										

Fig. 3

Printout of USER'S DATA

Parameter REGISTER, ENTRY DELAY, DURATION, REST, DYNAMICS

COMPUTED DATA VARIANT 1										
TEMPO	75									
TOTAL DURATION	20									
INSTRUMENT GROUPS	1	1	1							
REGISTER GROUPS	1	1	1							
ENTRY GROUPS	7	1	1							
DURATION GROUPS	10	1	1							
DYNAMIC GROUPS	6	1	1							
REST GROUPS	1	1	1							
NUMBER OF ATTACKS PER LAYER	20									
CHORD SIZE INDEPENDENT										
SEQUENCE OF CHORD SIZES	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1
NUMBER OF TONES PER LAYER	20									
HIERARCHY FOR LAYER	1	4	5	1	2	6	3	7		

Fig. 4

PROJECT 2 – Printout of GROUPS and HIERARCHY

COMPUTED DATA VARIANT 1

ENTRY DELAY

ENSEMBLE : 7 8 9 10 11 12 13 14

10 11 8 8 12 11 9 13 11 14 9 10 14 11 9 12

9 11 13

DURATION

INSTRUMENT

ENSEMBLE : 1 1

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

1 1 1 1

HARMONY

2 8 1 7 12 11 5 9 6 3 10 4 11 3 5 2

10 7 4 12

INTENSITY

ENSEMBLE : 6 1 2 3 4 5 6

1 5 3 4 6 2 5 6 2 3 4 1 2 5 1 3

6 4 2 1

REGISTER

ENSEMBLE : 1 1

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

1 1 1 1

REST

ENSEMBLE : 1 1

REL.T.	ABS.T.	INDEX	TIME	REST
3.70	3.70	7	4.53	.01
2.93	7.46	11	9.11	.01
2.05	11.16	14	12.14	.01
2.90	15.04	18	15.31	.01
4.67	19.98			

Fig. 5

PROJECT 2 – Printout of "ENSEMBLE" and ORDER of elements

VARIANT 1

	Instrument	Mode	Pitch	Intensity	Entry	End	Comment
1	KL	–	402	PP	.00	.72	
2			408	F	.72	1.61	
3			301	MP	1.61	2.07	
4			207	MF	2.07	2.53	
5			412	FF	2.53	3.64	
6			411	P	3.64	4.54	
7			405	F	4.54	5.12	
8			509	FF	5.12	6.50	
9			506	P	6.50	7.39	
10			703	MP	7.39	9.12	
11			210	MF	9.12	9.70	
12			404	PP	9.70	10.42	
13			611	P	10.42	12.15	
14			503	F	12.15	13.04	
15			405	PP	13.04	13.62	
16			602	MP	13.62	14.73	
17			210	FF	14.73	15.32	
18			407	MF	15.32	16.21	
19			704	P	16.21	17.59	
20			612	PP	17.59	18.97	

Fig. 6

PROJECT 2 – Printout of SCORE, TIME in seconds

VARIANT 1

Meter	Pitch	Begin	End	Dyn	Mode
1	402	81		PP	–
1	402		88		
1	408	88		F	–
3	408		81		
3	301	81		MP	–
3	301		86		
3	207	86		MF	–
4	207		62		
4	412	62		FF	–
5	412		75		
5	411	75		P	–
6	411		76		
6	405	76		F	–
7	405		53		
7	509	53		FF	–
9	509		82		
9	506	82		P	–
10	506		42		
10	703	42		MP	–
12	703		53		
12	210	53		MF	–
13	210		82		
13	404	82		PP	–
14	404		81		
14	611	81		P	–
16	611		52		
16	503	52		F	–
17	503		32		
17	405	32		PP	–
18	405		81		
18	602	81		MP	–
19	602		74		
19	210	74		FF	–
20	210		72		
20	407	72		MF	–
21	407		73		
21	704	73		P	–
23	704		11		
23	612	11		PP	–
24	612		76		

Fig. 7
PROJECT 2 – Printout of PARTS, TIME in metrical positions

Variante 2

Fig. 8
PROJECT 2 – Structure, Variant 2

Automation in the electronic studio
A system of voltage control has been developed in the studio at Utrecht; an important component of this system is a "variable function generator", (a description of which will appear in Volume 2 of Electronic Music Reports), with which up to 200 amplitudes (direct voltage levels) can be set. The individual levels and the period of all the levels can be produced periodically and aperiodically, by hand and controlled by impulses. According to the sampling rate, either stationary sounds or direct voltages of changing amplitude are produced, which can be used to control voltage-dependent amplifiers, oscillators or filters. The functions of this apparatus can easily be programmed for a computer, which means that it can also serve as a simulator for computer programmes. A few examples from an electronic composition by the author, carried out with the aid of the variable function generator, will show some possibilities of studio automation which can readily be dealt with by a computer.

This composition bears the title "Functions" , the names of colours (e.g. *Function Red*) being used to distinguish several variants of the work. The starting-point of the "Functions" was a curve consisting of 48 levels, which was set at the function generator (Fig. 9). Periodic samples resulted in sounds rich in partials, as was also the case with frequency modulation by using the same curve to control an oscillator. Slow sampling caused square impulses of various amplitudes. The control pulses came from a noise generator, which is the reason for the aperiodic rhythm. Slower aperiodic control pulses and the use of an oscillator resulted in a kind of tune (pitches leaping up and down, but also glissando transitions after the curve is filtered), which was later used to ring-modulate the basic sounds mentioned first. Lastly, the original curve and an on-off signal (0-1 signal) were used to control a voltage-dependent amplifier (amplitude modulator), on the one hand for dynamic articulation, on the other hand to control the dynamic proportion of reverberation or a filter.

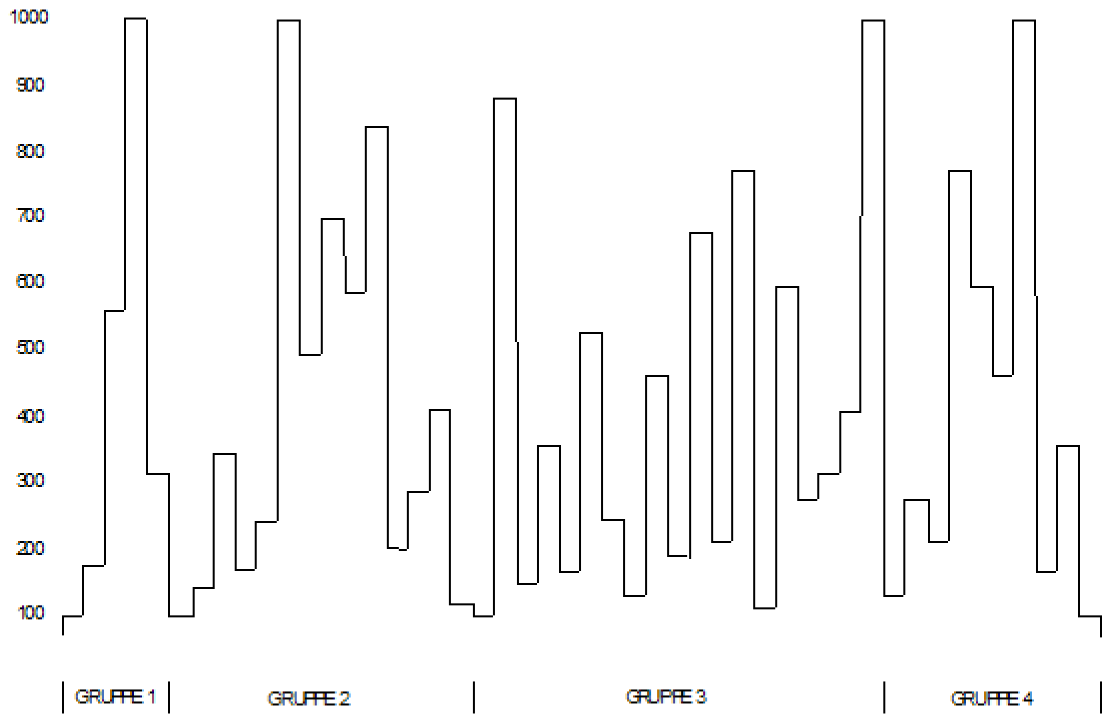


Fig. 9
Curve for "FUNCTIONS"

All the signals mentioned were stored on tape in several variants. Thirty-six circuit diagrams indicate the manner in which basic sounds and control voltages should be combined for sound production. Fig. 10 shows one of these diagrams. (The basic material was ring-modulated with a control voltage which in its turn was chopped up rhythmically by another control signal; the result was filtered and mixed with amplitude-controlled reverberation.) The formal assembly of the final version was calculated by the computer, which determined for each circuit diagram the variants, the duration of the sound and its position (in time) in the piece. In *Function Red*, the durations were between 8 seconds and 64 seconds, thus keeping tape editing to a minimum.

The same circuit elements (demodulators, modulators, level switches) were also used to form variants in such a way that an existing version of the "Functions" could be transformed in its entirety. All the versions are four track; one derivative was made by using two tracks to produce one new track: tracks 1 and 2, tracks 2 and 3, 3 and 4, 4 and 1 were combined to make the new tracks, 1, 2, 3 and 4. In each case one track provided the sound material and the other the control signals.

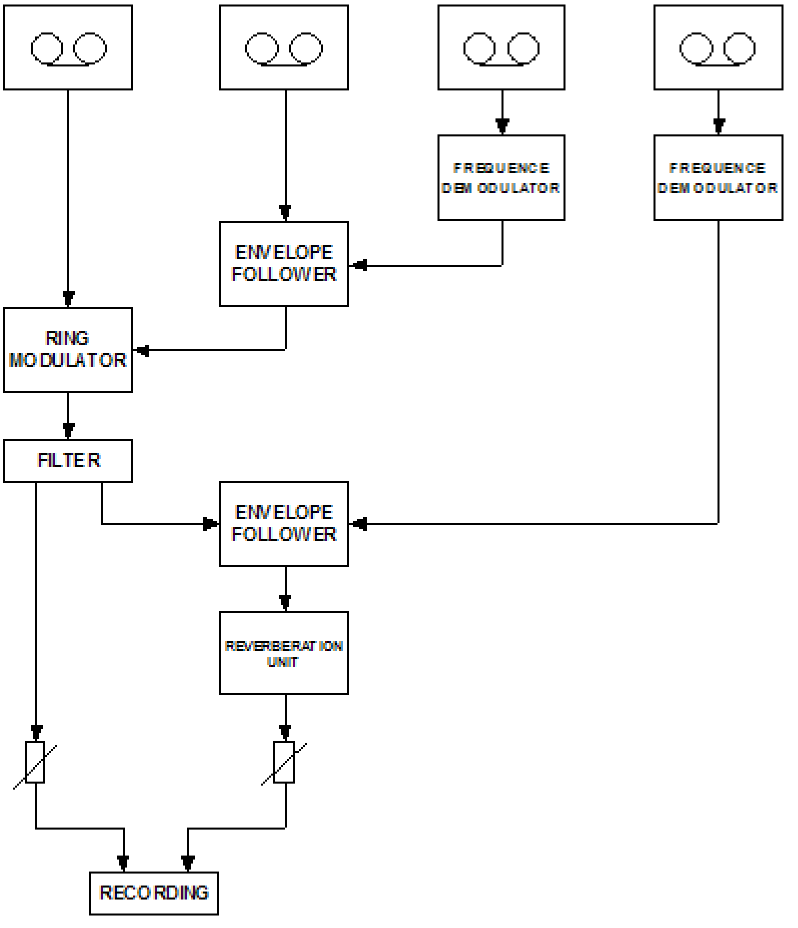


Fig. 10
FUNCTIONS – Wiring diagram 27

Sound production
Sound production with the computer at Utrecht is still only a plan; but this plan will be carried out, starting in 1971. As opposed to programmes based on stationary spectra or familiar types of sounds, the composer will be able to construct the waveform from amplitude and time-values. The sound will thus be the result of a compositional process, as is otherwise the structure made up of sounds. The composer defines lists of data for amplitudes and time-values; these values will be put together by means of selection principles to form sound segments. Each segment begins and ends with an amplitude of zero. A permutation list, provided by the composer, determines the order of the segments, which may contain any number of repetitions. All known parameters of sound such as duration, dynamics or timbre thus become functions of the constructional principle. The amplitude values which are distributed in time can be connected in various ways, either to form square waves, triangular waves or flowing curve forms. Suitable data input will also be able to produce familiar timbres (e.g. those of musical instruments).

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