Computer programs which play music with microtones

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ORPHEUS programs for the SOLIDAC computer accept an input of transcribed (solo-voice) musical scores which can then be played with facilities for overall or piecewise modifications.

Transcription rules, console operations and storage principles are described, to explain implicit and explicit possibilities for making microtone distinctions of tuning.

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General Introduction

Musical possibilities with SOLIDAC

SOLIDAC is a small general-purpose digital computer, built and largely designed by Barr and Stroud Ltd. It was intended for instructional use in Glasgow University. The design dates from 1959, and manufacture was completed in 1963. The computer is wholly transistorised, with ferrite-core storage for 1,024 words of 20 bits, and a basic pulse frequency of 30,000 Hz.

Notwithstanding these restrictions of size and speed, SOLIDAC has been programmed to provide for a variety of applications involving directly audible musical output. This is obtained by attaching an amplifier and loudspeaker (conveniently, from a tape recorder) to terminals which are connected to an internal circuit in which a rectangular pulse can occur with a duration of about half a millisecond. The repetition frequency of these pulses can be varied, by suitable programming, to control the pitch of a note; and the number of repetitions can be varied, also, to control the duration.

The volume-level of a note is unvarying, and the 'attack' is instantaneous, with liability to a faint click-sound from starting transients. (There is some scope to reduce this by using tone-control facilities.) The notes have a good content of higher harmonics—increasingly so, at lower pitches, but with some progressive reduction of general volume-level—and the timbre is not unlike that of conventional wind or woodwind instruments. Musical expression can be valuably improved by making use of grace-notes or similar decoration, by introducing rubato and rallentando, and by providing small explicit rests, for staccato.

Integer numbers and pitch limitations

Because of the manner of working of the computer, pitch can be more directly discussed in terms of the periodic time of a note (inversely proportional to the repetition frequency, as more usually considered). The periodic time of any note must be an integral multiple of the periodic time of the 30,000-Hz basic pulses, since the initiation-time of each half-millisecond pulse depends on the arrival of one of these pulses.

The integer multipliers involved are limited on one side by the need to provide means of control of the duration of a note, and on the other side by the desirability of using 11-bit modification, for faster operation. The smallest multiple then involves a factor of 39, and the largest, a factor of 1,023. The associated frequencies are corresponding submultiples of a frequency of 30,000 Hz. The highest available note has a frequency of 769 Hz—roughly, an octave-and-a-half above middle C—and the lowest note has a frequency of 29 Hz—about the limit of the musical range, like the lowest-pitch pipe used by organ-builders.

(The large multiples, for very low notes, are little used in direct play: but they are convenient in some applications where the computer is made to play lower in pitch and slower in speed by a factor of either 2 or 4, to give finer pitch-discrimination in a tape-recording intended for playback at doubled or quadrupled speed.)

Duration limits and related considerations

The duration of a note must involve an integral number of repetition-periods during which the note is sounding, and the exact determination of rhythm requires that the sounding duration should be appropriately curtailed to allow for a short (and constant) period of silence during which some computer work has to be done at the change of a note.

This silent time is itself conveniently expressed in terms of a number of basic-pulse periods. In different programmes—of varying complication—it can range from about 300 pulses (10 milliseconds) to about 2,000 pulses (65 milliseconds). Even at the higher limit this causes no break in an intended legato effect. (Staccato in fact requires the conscious programming of explicit short-duration rests.) This is to some extent a physiological effect—a persistence of hearing, similar to persistence of vision—and it can be reinforced in practice by physical effects involving reverberation.

Another consideration has to be noted here. With notes of very short duration (grace-notes and other ornamentation), the actual sounding duration should not include too few pulse-repetitions, or an actual pitch-frequency will not be sufficiently well defined. A single pulse cannot define a pitch, even if it is meant to, and if grace-notes are to be better than percussive clicks, they should require a minimum of about six pulse-repetitions.

With a calculation time of say 1,500 pulses, this means that the highest note will have effective durations available between $(6 \times 39) + 1{,}500 \simeq 1{,}750$ pulses and $(1{,}023 \times 39) + 1{,}500 \simeq 40{,}000$ pulses: for the lowest note, the limits are about 7,650 pulses and 1,000,000 pulses. These durations run from 36 milliseconds to 1·33 seconds, for the top note, and from 0·25 seconds to about 30 seconds, for the bottom note. Limit durations for intermediate pitches can be determined similarly. Ranges of duration are thus more than sufficient for all ordinary musical needs.

Transcription and the varied play of staff-notation scores

Previous considerations are important in programming work, but understanding of them is not vital to musicians who may be interested in making use of the computer. This applies particularly to the ORPHEUS programs which allow the computer to play music after entry of a data tape which is as near to a straight transcription of a conventional score as can be secured within the conventions of five-hole teletape input.

A special feature of these programs is the fact that modifications to pitch and speed—independently of each other—are readily made by simple operations at the computer console: and changes of pitch and speed, as so determined, can easily be added as permanent modifications of a score tape—by simple hand-punching, in straightforward cases.

The ORPHEUS music is solo-voice, only. (Some limited harmony is available with another set of programs.) Full facilities as described are available for scores of just over 300 items (where the term *item* is used to denote an individual note or rest, or staccato-rest, or grace-note, or component note of an ornamentation). Abbreviations for repetitions—possibly with alternate continuations—can be handled with the equivalent of da capo al segno markings; apart from this, assembly of sections as compiled and stored can allow scores of about 550 items to be played with transpose and speed-change still available, or scores of about 750 items to be played directly—by over-writing the read routine, and possibly the alteration routines also, after preliminary use.

Microtone facilities, implicit and explicit

Although an input similar to a transcription of ordinary staff notation is used, the computer can in fact operate with microtone divisions of the octave, making necessary enharmonic shifts in transpositions. One program has four octaves of 53-tone division: others have four-and-a-half octaves of 31-tone or 19-tone division. In each case the score may be marked for the use of explicit tones of the scale concerned—with the finer divisions, by using signs for comma-interval raisings or lowerings of pitch, or a notation which includes semi-sharps and sesqui-sharps, in addition to to single and double sharps (and similarly for flats). This provides for notations which are already standard in 53-tone and 31-tone music.

With these finer divisions of the octave, it is possible to select sets of notes which provide better approximations to acoustically true intervals than can be had with the equal-tempered 12-tone division of modern keyboard instruments. They can allow distinctions of pitch which indeed are made in practice by vocalists and string-instrument players, when unaccompanied.

There are also programmes which use a 12-part division of the octave—either in a close approximation to equal temperament, or with an acoustically better tuning, similar to mean-tone temperament. In this latter case there is an automatic microtone-retuning of some notes when scale-changes take effect.

Accuracy of tuning

Since the loop-lengths which specify repetition periods for notes have to be determined as integral multiples of the period of the basic computer pulses, it is not possible to make all the intervals in a scale *exactly* equal. The tuning has to depart to some extent from theoretical perfection, with some increasing liability to error as the pitch increases.

However, the multiples used have been chosen to minimise this effect as much as possible; and in many cases the errors will remain below the limits of human pitch-perception.

If not all the notes of the scale are in simultaneous use, the actual pitch may be chosen to ensure that the larger errors occur for notes which are not actually required; and even when all notes are being used, a two-stage procedure is possible with recordings: speeds, rubato and rallentando can be determined or adjusted at the intended pitch, with some imperfections of tuning, before making a two- or four-fold drop of pitch and speed to secure better tuning for a recording which will have double- or quadruple-speed playback.

When a piece can be recorded using only the lowest two-and-a-half octaves, the worst errors of pitch or interval can be kept to less than one part in 200. This represents about one-twelfth of a semitone, applicable to a few extreme cases. The great majority of pitches and intervals then have errors which are less than the one-twentieth of a semitone which is about the limit of human pitch-discrimination.

Even in direct play in the higher octaves, the errors are still not so large as to destroy the advantages of using the more finely divided scales, rather than an equal-tempered scale of semitones.

Input, coding rules and console operations

Input to SOLIDAC is by five-hole teletype paper-tape, using the Ferranti code (as for the PEGASUS and SIRIUS computers). An account of the coding rules and console operations will give a more detailed picture of the nature and extent of the facilities which are available.

Transcription rules for staff notation scores

Titling, termination and da capo markings

A musical score—on five-hole tape, suitable for play by ORPHEUS—is primarily a sequence of *musical items* (notes of specified pitch and duration, or rests of specified duration): additionally there will be *location directives* and *parametric directives*; and the score may have a title incorporated, for convenience of identification and print-out.

Several scores may be assembled on a single tape. In this event, the later titles will be read, automatically, and must have a proper form. (When read, they will be output automatically by the tape punch: it may be preferable to use written titles and disconnect the punch—and the reader, after the initial read of the score—to remove extraneous noises during play.)

Titles which are to be output must be one or several strings of characters beginning with LS (letter shift) and ending with LF (line feed), each at the start of its score. The text of titles can be either in ordinary code, for standard printing, or in a directly-legible perforator code (which causes hash-printing)—or both; and tapes may of course be inserted over their titles, if preferred.

The end of a score must be signalised by an * (asterisk) character. This is a location directive (and the only obligatory one).

The other location directives are the parentheses (and), and the solidus symbol /: these are used for da capo al segno markings. Play will read the score up to a) symbol, and will then revert to read onwards from the associated (symbol. In the repeat, any part between a / symbol and the) symbol will be omitted. Nested parentheses are not permitted.

General markings for speed and transposition

There are two parametric directives, used to set speed and pitch—the crotchet number and the transpose number.

A crotchet number is obligatory at the start of a score (immediately after the titling, if any). This is punched as a decimal integer specifying crotchets per minute, terminated by either Sp (space) or CR (carriage return). Optionally, before later sections of a score, new crotchet numbers may be imposed: in this event each new number must be preceded by an = (equality) symbol. A crotchet number must be 30 or more.

A transpose number may be written at the start (after the crotchet number), and can be changed later in the score. This consists of an → (arrow) symbol, followed by a decimal integer terminated by Sp or CR: here, the integer may be negative, beginning with a − (minus) sign. A transpose number will ensure that the following score (or part-score) will be transposed—upwards, for positive numbers—by the stated number of steps of the octave division which is being used.

New crotchet or transpose numbers must not be supplied inside sections of scores which are enclosed by da capo parentheses. A + (plus) sign is optional before a crotchet number (after an = sign, if present), or before a positive transpose number (after the → sign).

Notes and rests: duration specification

For the main constituents of a score—notes and rests—a first group of symbols specify a duration, and then a second group specify a pitch (or signalise a rest).

The duration part of a coded musical item is either a single digit, possibly followed by a single + or − symbol: or else a two-digit decimal integer.

Single digits from 1 to 8 are used to specify the customary binary-sequence duration-symbols of staff notation, with the convention that 4 gives a quaver and 5 a crotchet: so 8 gives a full breve and 1 a hemi-demi-semiquaver. Appending a + gives a 3/2 increase of length, for a (singly) dotted note; appending a − gives a 2/3 reduction, for a note in a triplet. No more than one + or − symbol is allowable here.

The double-digit symbols allow finer distinctions of duration. Any single-digit symbol can be replaced by its twelve-fold multiple (to give 48 for a quaver and 60 for a crotchet) with equivalent effect. Other double-digit symbols then give suitably interpolated intermediate durations. A step of 7 in the two-digit number gives an exact or adequately approximate factor of 3/2 or 2/3. Steps of 5, 4, 3 similarly involve factors 4/3, 5/4, 6/5. This readily allows for double-dotted notes (with a step of 10 for a factor of 7/4), and for durations in groupings other than triplets. Modifications by one unit, or two, provide desirable facilities for rubato and rallentando.

Pitch-specification of notes, and standard accidentals

Ordinarily—with exceptions later to be noted—the duration coding is directly followed by a group of three symbols of which the first is LS (letter shift) and the last is FS (figure shift), the intermediate symbol being for a letter from A to G, or for an R (denoting a rest). Here A to G are used in the ordinary musical sense. For notes, there may next be a digit to indicate the octave in which the note occurs (a zero symbol for the lowest octave may be inserted or omitted, as preferred); and after this there may or may not be one (or more) accidentals indicated, before the item is terminated by a final Sp or CR. (The accidentals must not be written before an octave-numeral.) The octave numerals change on passage from a G to the next higher A.

Er (erase) symbols are disregarded throughout: blank tape (for ease of hand-punch alteration) can occur between items, or between the duration coding and the following LS. Sp symbols can occur where blank tape is allowed: CR and LF can intervene between items, as can all characters which cannot be the first (or only) character of a score-component.

Accidentals use + for sharp, and − for flat. These can be doubled (or even further replicated), for larger changes: in effect, there is a summation for multiple accidentals. Alternatively, × can be used for double-sharp, and = for double-flat.

Explicit accidentals for 31-tone music

With the 31-tone division (which gives 5 steps to the whole tones A–B, C–D, D–E, F–G, G–A, and 3 steps to the semitones B–C and E–F), sharps and flats involve two-step shifts. Each of the 31 tones can be identified by a single letter, possibly with a single symbol + − × or =. (There are then four pairs of synonyms, of which B× and D= are typical.)

However, in some contexts—such as music using septimal intervals—a terminology using semi- and sesqui-accidentals is used for 1-step and 3-step shifts: and the computer can accommodate this, using $>$ and $\geqslant$ for semi-sharp and sesqui-sharp, and / and $\neq$ for semi-flat and sesqui-flat.

Explicit accidentals for 53-tone music

For the 53-tone division, the preferable terminology is Pythagorean; this assumes 9 steps for a whole tone, 4 steps for a semi-tone, and 5 steps for a (single) sharp or flat. A single step here gives a close approximation to three microtone-intervals—the commas of Pythagoras and of Didymus, and the diaskhisma, which become equivalent when the skhisma (about one-fiftieth of a semitone) is considered negligible. Symbols are needed here for single-step shifts both up and down.

These single-comma pitch changes are specified by using symbols) or (immediately in front of the letter symbols: before the associated LS, on the tape, one or more of the parenthesis symbols can intervene, similarly to and possibly mixed with the blank tape or Sp symbols which are allowable after the duration coding.

Mnemonically the parentheses which provide the musical comma-symbols can be associated with inequality symbols applied to pitch-frequency: thus, a) suggests 'greater than', and gives a one-step rise of pitch, and a (suggesting 'less than' gives a one-step drop of pitch. Replicated parentheses have additive effect.

Just-intonation major scales are then given by notations

C D (E F G (A1 (B1 C1
G A1 (B1 C1 D1 (E1 (F1+ G1

and similarly: and a just-intonation descending melodic minor is given by

A1)G)F E D)C B A

with all necessary precision, in compact form.

A letter here need have no more than two comma-symbols appended, or else a sharp or flat with at most one comma-symbol, to select any desired one of the 53 tones: and there is no bar to the use of more elaborate synonyms, if these are preferred because of other musical associations.

Other interpretations of accidentals

The semi- and sesqui-accidentals are directly connected with the 31-tone division, and the comma symbols with the 53-tone division. But either form of the programme will make the best possible use of any symbols which it meets: comma-symbols (written as parentheses) will give single-step shifts with the 31-tone scale, whereas semi- and sesqui-accidentals will give 2- and 7-step shifts with the 53-tone scale.

There are 19-tone and 12-tone versions of ORPHEUS which will ignore commas and semi-accidentals, and treat sesqui-accidentals as double. There is also an alternative 53-tone version which makes a departure from the more systematic Pythagorean convention to the less systematic notation used by Daniélou (following Indian practice). Here, symbols A, B, . . . , G refer to notes in the just-intonation major scale of C. Use of a sharp (for F sharp) here involves a rise of 5 steps, and flats (attached to B, E, A and D) involve drops of 4 steps.

On this basis Daniélou uses square and double-line note-head symbols, orthogonally or diagonally—in addition to the usual oval ones—to show comma-modifications (in a staff-notation score), for the various Indian ragas. With the alternative 53-step programme, parentheses can directly correspond with Daniélou's graphic symbolism.

Console operations with ORPHEUS

Modes of running, stops and optional stops

Immediately after the load of any particular version of the ORPHEUS program, there will be a halt on a stop which demands the supply of a score tape. Subsequently, the program will be running in some one or other of four operating modes, or else will be halted on some one or other of four main stops—or possibly on one or other of three additional (optional) stops.

The stops are signalised by different patterns of lights in a 20-bit binary display register. Console operations involve an associated set of 20 hand switches.

Input monitoring

An improper crotchet number (less than 30) will cause READ to terminate, with a return to the READ STOP. Other errors of coding—possibly after many correctly-coded notes—will cause cessation of READ, with a transfer to the ALERT STOP: and this will happen also if there is an implicit demand (in a correctly coded score) for an unduly extreme pitch or duration.

If a score *is* successfully read to the end, this gives a guarantee that it can be correctly played as demanded. A score which is of excessive length will be read only up to the point where it would overflow storage, when there is a transfer to the ALERT STOP.

On resumption of running from the ALERT STOP, there is an immediate passage to the CONTROL STOP (with a change of indicator displays).

From the CONTROL STOP—see later—a choice can then be made to have PLAY up to the point of termination; or possibly to have a new READ after hand-punched alteration of the input tape. This alteration might be a simple change of crotchet number or transpose number, if the trouble was transgression of a duration- or pitch-limit.

READ and PLAY

At the end of a successful READ, the program will begin PLAY—after a pre-set pause—if all hand switches then have zero settings. Otherwise it will proceed to the CONTROL STOP. At the end of PLAY, the program will proceed to a new READ, or to the CONTROL STOP, similarly.

If all hand switches remain zero, READ and PLAY will continue for a succession of scores assembled on a single tape. Programmed halts, after selected scores, and a final stop (on the READ STOP in both cases) can be arranged by inserting the symbols =0 which operate as an improper crotchet number.

During either READ or PLAY, putting *all* hand switches to non-zero will give an immediate transfer to the CONTROL STOP.

After an abruptly discontinued READ, satisfactory PLAY can take place up to the point of discontinuation. With an abruptly discontinued PLAY, an *immediately* following PLAY may be incorrect because da capo alternations were abandoned in the wrong phase; but—if so—one replay (possibly with the sound suppressed!) is bound to restore the score to a correct form for later use.

Options from the CONTROL STOP: TRANSPOSE and SPEED-CHANGE

From the CONTROL STOP, the program will proceed to PLAY if all hand switches are set to zero, and to READ if the extreme switches at *both* ends of the row are set non-zero.

In other circumstances the operator can set up for TRANSPOSE or for SPEED-CHANGE, and the program will check whether the proposed alteration is possible, within overall limitations. If not, it will go to the ALERT STOP; and continuation after the ALERT STOP will give a return to the CONTROL STOP, with the original score undisturbed. A feasible alteration will be made by appropriate alteration of the whole of the stored score, before a return to the CONTROL STOP (where displays are available to show an altered crotchet or transpose number).

Console-alteration procedures

Procedures for console alteration are particularly simple when only 12 notes are used in the octave. Explicit use of an ALTERATION STOP—as in other versions—is not then required, and alterations are determined by an implicit attention to hand-switch positions in settings made during a halt on the CONTROL STOP. Depression of a single (non-extreme) switch will cause SPEED-CHANGE—FASTER, the farther it is to the right, and SLOWER, the farther it is to the left. TRANSPOSE UP requires depression of the right-hand-end switch, and TRANSPOSE DOWN, depression of the left-hand-end switch. The number of semitones in the transposition—if more than *one*—is set by the distance from this end to another (non-extreme) depressed switch.

Speed changes in geometric progression between about 6% and two-and-a-half times, or transpositions by semitones through intervals up to and including a twelfth (19 semitones)—either way, in both cases—can then be made by one-pass operations.

Light displays, optional stops and further indications

The 20-bit light display which can signalise a type of stop has (in all) six alternative displays, selected by a rotary switch. Another (11-bit) display has eight alternatives. The musical programs use these displays to give useful information to the operator or observer. During running, the 20 bits can be made to show the stored form of each note (or rest) which is of immediate concern, and the 11 bits can indicate the relevant serial number in the score. On the CONTROL STOP, 11-bit displays provide information from which feasible limits of TRANSPOSE and SPEED-CHANGE can readily be determined, without need of exploratory trial.

Additional use of other displays can be made during all modes of running, if a hand-switch optional-stop facility is used to make them proceed by single notes, with intervening stops. READ, TRANSPOSE and SPEED-CHANGE will then have halts to display information relative to each note as it is written into storage. PLAY will have halts to show similar information both before and after the play of each individual note.

Storage of scores, and methods of alteration

Termination and da capo markers

In the 20-bit storage of a machine order, from most-significant digits downwards, there are 6 bits to specify a function coding, 3 bits to specify a choice of any one of seven modifiers, or none, and 11 bits to contain an integer or store-location number which may be involved in 11-bit modification facilities.

In storing a music score for ORPHEUS, the 20 bits of storage are employed as follows. (Here we number the digit-positions onwards from 1 at the least-significant end.)

A stored item with zero in all positions is the terminator of a playing score. This will be stored as a final item when a terminating asterisk is met in a successful READ. It will also be inserted appropriately if READ is stopped by coding errors, transgression of pitch or count limits, or excess length of score; or if READ is abruptly discontinued.

Apart from this, the stored item is a musical item—note or rest—only if there is zero in both positions 11 and 20. In other cases the element is a da capo marker. It may be simplest to deal with da capo markers first.

Score elements—including da capo markers—are considered to have serial numbering from 1 onwards (and accessed by having this number as a B7 modifier). Da capo markers store the serial number of the element which may have to be jumped to, in place of continuing serially, after the da capo marker is read. This number is stored at the low end (where 10 bits are available).

Non-zero in position 20 then indicates that a jump is to be *effective*, and non-zero in position 11 then indicates that the jump is to be *alternately effective and ineffective*. If there is non-zero in position 11, the digit in position 20 will alter during successive phases of PLAY.

(Da capo markers are by-passed by note-displays: their presence and effect is shown by jumps occurring in the serial-number display.)

Types of da capo markers

Immediately after READ, therefore, there will be storage for an *effective* jump where there was a); and this will be *alternating* if there was no associated /, but *non-alternating* if there is a preceding / associated with it. At the position of a /, there will be a *non-effective but alternating* jump. No stored entry is needed where there was a (. The jump from a) location is directed to the note which followed the associated (, in the score, and the jump from a / location (if any) is directed to the entry which followed the associated) entry, both in the score and in the store.

To provide suitably for abrupt discontinuation of READ, a / will first cause insertion of a jump to the immediately following entry (actually, a non-effective alternating jump). This is appropriately overwritten if the following) is read before the termination takes effect.

(There is no break of timing, in PLAY, for da capo jumps: an equivalent delay is supplied where they do not occur. Da capo symbols ( ) or (/)—used with no intervening note-symbols—form a means of introducing very small rests for staccato, of shorter duration than a minimum explicitly-specified rest.)

Field-divisions in note- and rest-storage

In the case of notes and rests, the positions 19 to 12 and 10 to 1 allow eight bits and ten bits, respectively, to specify pitch (or rest), and duration (for either). The mode of storage is directed to allowing for console alterations of pitch and speed, but otherwise towards a maximum economy of computer operations—and timing —during PLAY. To this end, the READ phase involves an appreciable amount of compilation (which serves for monitor purposes also).

For this reason, the duration is stored as the actual count which will be needed in a note-generator loop: with any given duration, this count will increase with increasing pitch of the note.

With zero in positions 20 and 11, the item will be a rest if all positions between 19 and 12 (inclusive) have zero: otherwise it is a note. The pitch of a note is specified in storage by giving a serial position in the scale-division, in terms of an octave number and a pitch-residual number, with increasing pitch involving ever larger numbers.

The residuals run from 1 to 53, or to 31, or similarly, according to the octave division in use. The value of the residual is stored in positions 17 to 12, or 16 to 12; and two bits (to select among four octaves) are available in the higher positions 19 and 18, for 53-part division, and three bits (for more than four octaves) in the other cases.

Requirements as scores are read from storage

During PLAY, the octave- and residual-codings are used to fetch a pitch integer, which can then select a note-generator and (if need be) adjust it to an appropriate loop-length for the intended pitch: the loop is then traversed with a count suitable for the intended duration.

In the console-controlled alterations, TRANSPOSE requires an appropriate conversion of the octave- and residual-numbers, to record the new pitch; and use of the old and new pitch codes to find loop-length values for proportionate conversion of the stored count, to secure unaltered duration. With SPEED-CHANGE, the pitch coding is unaltered, but the loop-length has still to be found and used, since the overall duration has to be determined with inclusion of an unchanged silent calculation-time.

Monitor procedures

During READ, improper counts and pitch numbers are detected and failed (as well as improper codings). When there is no failure, values for six extreme cases are noted—the highest and lowest pitches, the largest and smallest counts (exclusive of those for rests), and ratios specifying maximum and minimum possible speed-changes. The first four set limitations for TRANSPOSE, and the last two set limitations for SPEED-CHANGE. Additionally, copies of storage items involved in the last four limit cases are recorded immediately before the actual start of the score, as stored.

For console alterations, TRANSPOSE first checks that pitch limits are not being transgressed directly. Both TRANSPOSE and SPEED-CHANGE then examine whether they could successfully transform the four preliminary extreme-case items at the head of the score, without failure from an excessive count (or zero count). If failure would occur, this can be noted without any disturbance of storage: otherwise, new extreme limits and new score-entries for the extreme cases are obtained —just as during READ—as an approved alteration proceeds through to the end of the stored score proper, before return to the CONTROL STOP.

Concluding remarks

This account has been written as a record of the programs and their facilities, partly for the benefit of some musicians who have expressed interest in possible use of the facilities which SOLIDAC can provide. The author will be glad to hear from any others who may be similarly interested.

Much current work in the field of computer music concentrates on the production of novel timbres. Facilities with SOLIDAC gave little scope for this. Instead, they have given a means—within solo-voice restrictions—of providing possibilities of finer control of pitch which have been sought by various musicians—past, and present, alike. Some have aimed to achieve this by building special-purpose instruments which for the most part have been hampered by a shortage of skilled executants.

As planned here, however, the computer will act as an automatic executant: the principal problem is to obtain or prepare scores which will suitably and valuably exploit these potentialities. It is already quite clear that tuning distinctions here involved are fully perceptible to many, and not only to trained musicians.

Facilities with SOLIDAC allow ample scope for experimentation, with immediate control from audible output. Revisions and improvements can readily be made, both to scores and to the manner of their playing, and any changes made can easily be put on permanent record—possibly for further stages of revision and improvement.

This work may be of interest as a pointer towards feasible computer possibilities which might attract musicians to a greater extent than many currently seem to realise.

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